MERCURY EMISSIONS: STATE OF THE SCIENCE AND TECHNOLOGY

HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTH CONGRESS

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MERCURY EMISSIONS: STATE OF THE SCIENCE AND TECHNOLOGY

WEDNESDAY, NOVEMBER 5, 2003

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:08 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Vernon J. Ehlers [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Mercury Emissions: State of the Science and Technology

Wednesday November 5, 2003
2:00 PM – 4:00 PM
2318 Rayburn House Office Building (WEBCAST)

Witness List

Dr. Thomas Burke
Professor and Associate Chair,
Department of Health Policy and Management, Johns Hopkins University Bloomberg School of Public Health

Dr. David Krabbenhoft
Research Scientist,
United States Geological Survey

Dr. George Offen
Senior Technical Leader, Air Emission and Byproduct Management,
Electric Power Research Institute

Mr. Ken Colburn
Executive Director,
Northeast States for Coordinated Air Use Management

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HEARING CHARTER

SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND STANDARDS
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Mercury Emissions: State of the Science and Technology

WEDNESDAY, NOVEMBER 5, 2003
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On November 5, 2003 at 2:00 p.m., the Subcommittee on Environment, Technology, and Standards of the House Science Committee will hold a hearing on that state of the science and technology regarding mercury emissions. The subcommittee will hear testimony on the health effects of mercury, the transport and fate of mercury in the environment, and the technologies that are being developed to control mercury emissions from coal-fired power plants.

The Committee plans to explore several questions, including:

- What do we know about the relationship between mercury exposure from fish consumption and adverse human health effects?
- To what extent is mercury deposition in the environment local, regional, or global?
- What do we know about how different kinds of mercury become available in the environment in a manner that can adversely affect human health? Is there a difference between new and old mercury and between anthropogenic and naturally produced mercury?
- What technologies are available or being developed to control mercury pollution from power plants? What do we know about the effectiveness and cost of these technologies?

Witnesses

Dr. Thomas Burke, Professor and Associate Chair, Department of Health Policy and Management, Johns Hopkins University Bloomberg School of Public Health. Dr. Burke served as a member of the National Academy of Sciences' Committee on the Toxicological Effects of Mercury. He received his Ph.D. in epidemiology from the University of Pennsylvania.

Dr. David Krabbenhoft, Research Scientist, United States Geological Survey. Dr. Krabbenhoft is a principal investigator on the Mercury Experiment to Assess Atmospheric Loading in Canada and the U.S. (METAALICUS) project. He received his Ph.D. in geochemistry and hydrogeology from the University of Wisconsin-Madison.

Dr. George Offen, Senior Technical Leader, Air Emission and Byproduct Management, Electric Power Research Institute (EPRI), the research arm of the utility industry. Dr. Offen manages EPRI's research and development program to reduce nitrogen oxides, sulfur dioxide particulate and toxic emissions from utilities. He received his Ph.D. in mechanical engineering from Stanford University.

Mr. Ken Colburn, Executive Director, Northeast States for Coordinated Air Use Management (NESCAUM). Prior to joining NESCAUM, Mr. Colburn served as New Hampshire's air director. He received his M.B.A. from the University of New Hampshire.

General Background

Under the Clean Air Act, the Environmental Protection Agency (EPA) is required to regulate mercury emissions from coal-fired power plants. Under a consent decree, the agency has agreed to promulgate a Maximum Available Control Technology (MACT) regulation by December 15, 2003. At the same time, the agency has proposed, through the Clear Skies Act, to regulate mercury emissions as part of a

multi-pollutant trading scheme, and several other multi-pollutant bills are also pending in Congress.

There is significant debate about how and to what extent mercury emissions should be regulated. There are many critical science and technology questions that underpin this debate. These include: what do we know about the adverse health effects of mercury?; to what extent do mercury emissions deposit locally?; is newly deposited mercury more reactive than legacy mercury?; what is the state of technology development to control and monitor mercury? The state of the science and technology must be well understood in determining the best course to follow in mercury regulation.

Issues

- **Do the levels at which the U.S. population is exposed to mercury through fish consumption have an adverse health effect?**

According to the Centers for Disease Control, eight percent of U.S. women of childbearing age have mercury blood levels that exceed those considered safe by the EPA. People are exposed to mercury through consumption of contaminated fish. In 2000, a panel of the National Research Council (the operating agency of the National Academy of Sciences) assessed the state of the science regarding the health effects of methylmercury from fish consumption. (Methylmercury is the form of mercury that accumulates in the food chain.) The panel examined epidemiological studies, animal studies, and other relevant data and concluded that there is an adverse health effect from methylmercury through fish consumption. However, in 2003, an update of one of the largest epidemiological studies, conducted in the Seychelles Islands, showed no effect from fish consumption.

- **Is mercury deposition local, regional or global?**

The extent to which mercury deposition is local is an important factor in determining whether mercury emissions should be reduced through a trading scheme or at every plant. Trading schemes assume that the benefit will be the same regardless of where the emissions reductions are achieved, i.e., that there is little or no local impact of the pollutant. The science of mercury cycling through the environment is complex, and deposition patterns depend on the form of the mercury. Studies have shown mercury deposition far from sources, demonstrating that deposition can be global. However, there appears to be a gradient of deposition, with highest deposition downwind and close to sources. The hearing will examine what we know about the local effects of mercury emissions from power plants.

- **Would slowing emissions of mercury from power plants decrease mercury levels in fish?**

There are large amounts of legacy mercury (from both man-made and natural sources) already in the environment. Because of this, critics of regulation argue that any reduction in current emissions will be overwhelmed by mercury already in the environment. However, recent research results suggest that new mercury may be more active than old mercury, indicating that achieving reductions now would have an effect on levels in fish. Additionally, mercury emissions from municipal and medical waste incinerators have been regulated since the mid-90s, and in Florida (where there are a large number of these incinerators), levels of mercury in wildlife have decreased substantially since the regulations were put in place. The hearing will examine what we know about the relative reactivity of new mercury vs. legacy mercury.

- **What levels of reductions are or will likely be feasible?**

At some plants, mercury removal rates of more than 90 percent have been shown using technologies that are primarily intended to remove other pollutants such as sulfur dioxide, nitrogen oxides and particulate matter. However, the type of coal used largely determines the type of technology needed to remove mercury. Plants that use sub-bituminous coal (found in the Western U.S.) will not likely see large reductions from existing technologies and will probably have to use a new technology such as activated carbon injection. The hearing will examine what kind of reductions will result, and at what cost, from existing technologies and technologies under development.

Detailed Background

Health Effects

Mercury is widespread and persistent in the environment. At high-level exposures, mercury is a serious neurotoxin and instances of population poisonings have

been well documented. The U.S. population is primarily exposed to mercury in low doses through fish consumption (and not through breathing it in from the air like many other pollutants). The form of mercury that is found in fish is methylmercury (MeHg). In 2000, a National Research Council (NRC—the operating agency of the National Academy of Sciences) panel evaluated what we know about the health effects of mercury. Reviewing the three major epidemiological studies (Faroe Islands, New Zealand and preliminary results from the Seychelles) as well as animal studies, the panel found that a range of health effects has been observed with severity varying primarily with the size of the dose. The report stated that the fetus is the most sensitive, and prenatal exposures have been shown to interfere with the growth and migration of neurons and can cause irreversible damage to the developing central nervous system. At the low dose exposure that is associated with fish consumption by the mother, infants may appear normal during the first few months of life, but later display deficits in subtle neurological endpoints such as IQ. The report also noted that there is evidence that MeHg affects other systems as well—a correlation has been found between consumption of contaminated fish and the risk of cardiovascular disease such as acute myocardial infarction.

The EPA has set the reference dose (RfD) for mercury based on the Faroe Islands study. (A reference dose is an estimate of the daily exposure that the human population can withstand without an appreciable risk of adverse effects over a lifetime—or the level of exposure that can be considered safe.) A recent study released by the Centers for Disease Control and Prevention found that approximately eight percent of women of childbearing age in the U.S. had mercury levels exceeding the level considered safe by the Environmental Protection Agency for protecting the fetus. Mercury contamination in fish has led health departments in 45 states to issue freshwater fish consumption advisories. These advisories warn people to limit consumption or avoid altogether certain species of fish from certain bodies of water.

In the last several months, there has been significant debate about the health effects of mercury from fish consumption following the May 2003 publication of the Seychelles study, which found no effect of mercury from fish consumption (the Faroe Islands and New Zealand studies did show an effect). At the time the NRC report was issued in 2000, the panel reviewed preliminary results from the Seychelles study, and stated that, "because there is a large body of scientific evidence showing adverse neurodevelopmental effects, including well-designed epidemiological studies, the committee concludes that an RfD [reference dose] should not be derived from a study, such as the Seychelles study, that did not observe any association with MeHg."

Sources and Emissions

There are three major sources of anthropogenic mercury emissions—medical waste incinerators, municipal waste incinerators and coal-fired power plants. In addition, mercury is released from natural sources, such as volcanic eruptions and degassing and vaporization from the Earth's crust. The EPA estimates that worldwide emissions produced by human activities rival and may greatly exceed natural sources.

Total anthropogenic sources in the U.S. are approximately 158 tons per year. Coal burning power plants are currently the biggest source of anthropogenic mercury pollution in the U.S., producing approximately 48 tons per year (or 40 percent of U.S. anthropogenic emissions). The Federal Government does not currently regulate coal-fired utilities with respect to mercury. The EPA regulates the other two major sources, municipal and medical waste incinerators, at 90 and 94 percent reductions respectively.

Annual global emissions are estimated to range between 2,000 and 6,000 tons per year, of which China is believed to emit approximately 1,000 tons annually.

Emissions from Coal-Fired Power Plants

There are small amounts of mercury in coal. Once the coal is burned, the mercury becomes a gas and enters the atmosphere. Mercury is emitted from power plants in three forms—1) elemental mercury, 2) oxidized mercury (also called reactive mercury or ionic mercury) which is primarily mercury chloride, and 3) mercury attached to particulate matter. All three of these forms will eventually deposit in the environment and could cause adverse health effects, however the differences are important in terms of where they deposit in the environment and what technologies can be used to reduce them from power plants. The form of the mercury emission depends on the type of coal and the burning process. Both bituminous (Eastern) and sub-bituminous (Western) coal have approximately the same total quantity of mercury, but the form in which it is emitted varies. Bituminous coal (found primarily in the eastern U.S.) contains chlorine and so when this type of coal is burned, approxi-

mately 70–80 percent of emissions are oxidized mercury. Sub-bituminous coal (found primarily in the western U.S.) does not contain chlorine and so approximately 70–80 percent of emissions are elemental mercury. The amount of mercury attached to particles depends upon how efficient the burning process is—the less efficient, the more particulate mercury will be emitted. The total quantity of mercury emissions is similar between the various types of coal.

Deposition

Where mercury deposits (locally, regionally or globally) once it is released from the power plant is a major source of debate because of its implications for regulation. If mercury deposition is primarily global, then regulation through a trading scheme makes sense. Regulation through trading programs assumes that it does not matter where the reductions are achieved, and that there is little or no local health effect from the emissions. However, if deposition is primarily local, then trading pollutants can lead to "hot spots" because certain plants will buy credits instead of achieving reductions. If there is a significant local health effect from emissions, then regulation should be done at each utility to address this local effect.

In addition, if mercury circulates globally, then since the proportion of U.S. emissions as compared to global emissions is small, it would be difficult to trace unilateral emissions reductions to health improvements in the U.S. However, if mercury deposits locally or regionally, reductions in the U.S. will likely lead to health improvement in the U.S.

This is an area where the science is not clear. The past 15 years of research have revealed widespread mercury contamination globally from diffuse sources. However mercury is not evenly distributed, and higher levels have been observed downwind from sources. The key to understanding this phenomenon is unraveling the complexities of how mercury transforms from one form to another in the environment. Deposition patterns also depend on the form of the mercury. Oxidized mercury is water-soluble and will deposit quickly, depending somewhat on weather conditions, likely within 60 miles of the source. Thus, the emission of oxidized mercury is primarily a local and regional issue. Elemental mercury can stay in the atmosphere for one to three years and enters the global pool of mercury. Eventually, all mercury in the atmosphere will be oxidized and deposited.

Researchers hypothesize that there is not an even blanket of mercury deposition across the globe, but that near emissions sources, there is greater deposition and then there is a gradient of lower deposition rates as you move farther away from sources. This is backed up with data from sediments—in more remote locations, there is significantly less mercury. According to data from mercury monitoring stations nationwide, the highest deposition rates occur in the southern Great Lakes, the Ohio Valley, the Northeast, and scattered areas of the Southeast—the areas around and downwind of coal-fired power plants. More research is needed to clarify this issue.

Control Technologies

The control technology that can be used to remove mercury from emissions depends on the type of coal burned (and thus the form of the mercury) as well as the plant's current emissions control technology configuration. Coal that has a high chlorine content (and thus produces oxidized mercury) can often be effectively controlled by scrubbers (used primarily to control sulfur dioxide). However, wet scrubbers are only effective at removing mercury chloride and so control can vary from less than 10 percent removal to greater than 90 percent removal depending on the type of coal burned. Fabric filters and electrostatic precipitators (ESP), used primarily to remove particulate matter, can effectively capture mercury that is attached to particles. For a wide variety of coal types and control configurations, recent full-scaled demonstrations have proven the effectiveness of powdered activated carbon (PAC) injection. This technology can be retrofit on existing boilers with minimal new capital equipment, and is effective on bituminous and sub-bituminous coals. However, PAC has yet to be used at a commercial scale.

An associated set of issues relates to the fact that the ash collected at power plants is used in industrial processes such as concrete production. The greater the carbon content of the ash, the less useful it is in these industrial processes. Large amounts of activated carbon are used to remove elemental mercury from the emissions. In order to keep the ash commercially viable, both an electrostatic precipitator and fabric filter are required - the ESP removes the mercury, and the ash (without mercury) can be collected in the fabric filter.

The cost of controlling mercury depends on the type of control technology used. Purchase of wet scrubbers, selective catalytic reducers, electrostatic precipitators and fabric filters are major capital investments, however all of these technologies

achieve mercury reductions as a co-benefit of other pollutant reductions. The extent to which these technologies are used will depend on the regulation of these other pollutants. Powdered activated carbon (PAC) does not require a major capital investment, and the primary cost is the purchase of the activated carbon sorbent itself. It is difficult to estimate how much PAC will cost because it is not yet used commercially, however costs have been estimated to range from less than $1 per megawatt hour (MWh) to $3 per MWh. PAC is also a percent reduction technology, meaning that the same amount of activated carbon will reduce a certain percentage of the mercury regardless of the total quantity. Therefore, PAC is more cost-effective the greater the amount of mercury present.

Monitoring Emissions

Measuring mercury emissions from utilities is a challenge because of the very small amount of mercury emitted by each source, but measurement technologies are improving. Currently, the best way to measure mercury emissions is through wet chemistry (the Ontario Hydro method). This method is accurate and will indicate the form of the mercury being emitted. The drawbacks are that it is expensive and measures a short snapshot in time (about two hours). Instrumentation methods, which continually measure mercury emissions, are currently under development.

Methylation

In order to cause adverse health effects, the dissolved mercury in water must become methylated (transformed into a new chemical compound with a methyl group attached). Researchers hypothesize that it is sulfur-reducing bacteria that methylate mercury. More research is needed on what causes mercury to become methylated. Chemical, biological and physical elements appear to affect methylation, and the limiting factor varies by location. For instance, in the Florida Everglades, a study has shown that sulfate load is the primary driver of methylation, while in the San Francisco Bay, it appears that wetland restoration spurs methylation, and the mode is unclear.

Once produced, methylmercury easily accumulates in the tissues of aquatic organisms and becomes more concentrated as it goes up the food chain. The concentration of a pollutant at the top of a food chain can be thousands or even millions of times greater than the concentration of the pollutant found in water. It is through fish consumption that mercury enters humans and other wildlife and causes health effects.

Witness Questions

Questions addressed to Dr. Thomas Burke:

- What did the National Research Council panel find about the relationship between low-dose mercury exposure and adverse human health effects? Are subpopulations differentially affected by mercury exposure?
- To what extent have studies published since the panel issued its report in 2000 altered our knowledge about the health effects of mercury?
- What are the future research needs with respect to understanding the health effects of mercury?

Questions addressed to Dr. David Krabbenhoft:

- What do we know about how mercury reacts in the atmosphere and what determines its deposition? To what extent is deposition local, regional or global?
- What do we know about the relative reactivity of old vs. new mercury and anthropogenic vs. natural mercury?
- What does research tell us about the extent to which reducing mercury deposition will reduce mercury levels in fish?
- What are the future research needs with respect to understanding how mercury cycles in the environment?

Questions addressed to Dr. George Offen and Mr. Ken Colburn:

- To what extent do control technologies in use today at utilities reduce mercury pollution from utilities? What determines the effectiveness of these technologies at reducing mercury emissions?
- What are the major technologies in development today to control mercury emissions from utilities? What do full-scale demonstrations tell us about the likely effectiveness and cost of these technologies?

- What are the major barriers to development of technologies to control mercury emissions from power plants?

Chairman EHLERS. Good afternoon. I am pleased to welcome everyone to this afternoon's hearing on the science and technology underlying a vital environmental and public health issue: mercury pollution.

Mr. Gutknecht just asked how I knew that he was interested in this issue, and I said it must be your mercurial disposition, which is unfair, because he is a very stable, solid person. But mercury has been around for a long time. We have been fascinated with it for a long time. And we have only, in the past few centuries, realized that it is a major public health issue.

This hearing is particularly timely. As most of you know, the Environmental Protection Agency is due to release a proposed mercury regulation this December, and there are also many bills pending in Congress to regulate mercury emissions from utilities, including the President's Clear Skies Act.

I am pleased to hold a hearing to examine the critical science and technology questions that underpin this policy debate. I expect that this subcommittee can serve as a forum for Members to undertake sober, calm, and fair-minded reviews of the science as Congress considers this important environmental and public health issue.

In my home state of mercury—pardon me, in my home state of Michigan—really, I am not from another planet. In my home state of Michigan, mercury pollution is a growing concern. People are exposed to mercury through eating contaminated fish. And of course, we have four of the Great Lakes touching our shores, and we have more boats registered per capita than any other state, so you know we have a lot of fisherman and many people eating fish. Since 1988, the Michigan Department of Community Health has issued a fish consumption advisory for all of Michigan's 11,000 inland lakes as a result of mercury contamination. And throughout the U.S., the Centers for Disease Control estimate that approximately eight percent of women of child-bearing age have levels of mercury in their blood that exceed the level considered safe by the Environmental Protection Agency. This is a matter of special concern for pregnant women.

We certainly have a problem, but the solution must be informed by science. We will hear today from experts from academia, Federal and State Government, and industry.

These witnesses will address a wide range of science and technology questions that inform the mercury debate. These include: "What do we know about and how precisely can we determine the relationship between adverse human health effects and mercury exposure from fish consumption? To what extent is mercury deposition in the environment local, regional, or global? What do we know about how different chemical forms of mercury become available in the environment in a manner that can adversely affect human health? And what technologies are available or are being developed to control mercury pollution from power plants?"

There is much to discuss and discover. Today, we want to thoughtfully review the current state of mercury pollution science and technology before new policies are put into place. We are here to learn. I look forward to the testimony.

[The prepared statement of Chairman Ehlers follows:]

PREPARED STATEMENT OF CHAIRMAN VERNON J. EHLERS

Good afternoon! Welcome to this afternoon's hearing on the science and technology underlying a vital environmental and public health issue—mercury pollution. This hearing is certainly timely. As most of you know, the Environmental Protection Agency is due to release a proposed mercury regulation this December, and there are also many bills pending in Congress to regulate mercury emissions from utilities, including the President's Clear Skies Act.

I am pleased to hold a hearing to examine the critical science and technology questions that underpin this policy debate. I expect that this subcommittee can serve as a forum for Members to undertake sober, calm, and fair-minded reviews of the science as Congress considers this important environmental and pubic health issue.

In my home state of Michigan, mercury pollution is a growing concern. People are exposed to mercury through eating contaminated fish. Since 1988, the Michigan Department of Community Health has issued a fish consumption advisory for all of Michigan's 11,000 inland lakes as a result of mercury contamination. And throughout the U.S., the Centers for Disease Control estimates that approximately 8 percent of women of childbearing age have levels of mercury in their blood that exceed the level considered safe by the Environmental Protection Agency.

We certainly have a problem. But the solution must be informed by science. We will hear today from experts from academia, Federal and State government, and industry.

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There is much to discuss and discover. Today we want to thoughtfully review the current state of mercury pollution science and technology, before new policies are put in place. We are here to learn. I look forward to the testimony.

Chairman EHLERS. The Chair now recognizes Congressman Mark Udall, the Ranking Minority Member on the Subcommittee, for his opening statement.

Mr. UDALL. Thank you, Mr. Chairman.

I want to welcome the panel and thank our distinguished Chairman for convening this hearing regarding mercury emission science and technology issues. The United States, as the Saudi Arabia of coal, has used this abundant resource to our advantage. Coal powered our Industrial Revolution and continues to provide energy to our power plants. However, as we are all aware, the use of coal has well documented negative environmental and health consequences. I am very encouraged, as I know the Chairman is and many of you here, that emission rates at coal-fired power plants for sulfur dioxide and nitrogen oxides have been cut by more than half since 1970. But I believe we can, and must, do more.

Clean air is an environmental and public health necessity. Mercury is a persistent, bioaccumulative toxin. In recent years, Federal and State governments have taken actions to reduce the use of mercury and to control its emission from medical and municipal waste incinerators. Now it is time to move forward with a cost-effective, rational plan to reduce mercury emissions from coal-fired power plants.

According to a 1997 EPA report to Congress, coal-fired power plants are the greatest human source of mercury emissions into our air. As a result, as the Chairman mentioned, the EPA is currently drafting a new standard to limit mercury emissions from coal-fired power plants. The level of the reduction has not yet been

determined, but we expect the regulations to be finalized this December for implementation in the year 2008.

I realize that utilities and the coal industry have concerns about the cost of controlling these emissions and the efficacy and the availability of control technologies. We should do what we can to ensure the costs are minimized and the technologies are sound. I believe there is an opportunity to develop, manufacture, and market control technologies here in the U.S. and to the rest of the world. We are, of course, not the only nation that utilizes coal. All you have to do is look at the great coal reserves in China as one example. We should be promoting technologies, clean technologies here and abroad, and we should move ahead aggressively to take advantage of these economic opportunities associated with this goal.

Today, our distinguished witnesses will give this committee some insights into the science and technology of reducing mercury emissions and suggest what further studies need to be completed in order to get the information to make knowledgeable policy decisions. This will help us, I believe, to get closer to determining how to use preventative measures to ensure that the risks of mercury pollution attributable to coal-fueled power plants are minimized, if not eliminated altogether.

Finally, Mr. Chairman, I know that at least one group, the Institute of Clean Air Companies, that wishes to contribute to the record for this hearing. Therefore, I would ask unanimous consent that the record be held open for 10 days to receive testimony from the Institute of Clean Air Companies and any other groups that may wish to submit testimony.

Chairman EHLERS. Without objection, so ordered.

Mr. UDALL. With that, Mr. Chairman, I would yield back with one other observation. I know you have very few political opponents, but I am sure there are some of them that would like to send you, if not to the moon, to Mercury, so we will keep in mind your comments earlier as we began the hearing.

[The prepared statement of Mr. Udall follows:]

PREPARED STATEMENT OF REPRESENTATIVE MARK UDALL

Mr. Chairman, thank you for convening this hearing regarding mercury emission science and technology issues.

The United States—as the “Saudi Arabia of coal”—has used this abundant resource to our advantage. Coal powered our industrial revolution and continues to provide energy for our power plants. However, as we are all aware, the use of coal has well-documented negative environmental and health consequences.

I am very encouraged by the fact that emission rates at coal-fired power plants for sulfur dioxide and nitrogen oxides have been cut by more than half since 1970—but I believe we can and must do more. Clean air is an environmental and public health necessity.

Mercury is a persistent, bio-accumulative toxin. In recent years, Federal and State governments have taken actions to reduce the use of mercury and to control its emission from medical and municipal waste incinerators. Now it is time to move forward with a cost-effective, rational plan to reduce mercury emissions from coal-fired power plants.

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I realize that utilities and the coal industry have concerns about the cost of controlling these emissions and the efficacy and availability of control technologies. We should do what we can to ensure the costs are minimized and the technologies are sound.

I believe there is an opportunity to develop, manufacture and market control technologies here in the U.S. and to the rest of the world. We are not the only nation that utilizes coal. We should be promoting cleaner technologies here and abroad, and we should move ahead aggressively to take advantage of the economic opportunities associated with this goal.

Today, our distinguished witnesses will give this committee some insights into the science and technology of reducing mercury emissions and suggest what further studies need to be completed in order to get the information needed to make knowledgeable decisions. This will help us get closer to determining how to use preventive measures to ensure that the risks of mercury pollution attributable to coal-fueled power plants are minimized, if not eliminated altogether.

Finally, Mr. Chairman, I know of at least one group—the Institute of Clean Air Companies—that wishes to contribute to the record for this hearing. Therefore, I ask for unanimous consent that the record be held open for ten days to receive testimony from the Institute of Clean Air Companies and any other groups that may wish to submit testimony.

Chairman EHLERS. Thank you. Since I have asthma, I am used to going without oxygen, so I might actually survive. The temperature might be a bit of a problem, however.

If there is no objection, all additional opening statements submitted by the Subcommittee Members will be added to the record. Without objection, so ordered.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK SMITH

I want to thank Chairman Ehlers and Ranking Member Udall for holding this hearing on the science of mercury emissions. And I would like to thank our witnesses for sharing their opinions with us today.

As a farmer, I understand that we are caretakers of the land. Farmers understand that what they put in the land can come out in our food and water. If we are not careful with the land we can do significant damage to its productive capacity, our environment, and animal and human health. Therefore, we must use responsible practices to maintain or improve the quality of our environment.

While farmers have learned much from thousands of years of tradition, modern science has revolutionized our understanding of agriculture. When we consider the impact of pollutants, such as mercury, science must be our guide in understanding the costs and benefits. This requires rigorous research, understanding where pollutants come from, where they go, what they do when they get there, and how they affect the land, animals and people.

We must be caretakers of our environment so that our children and grandchildren can enjoy and use it as much as we have. I applaud the Chairman and Ranking Member for guaranteeing that science is used in making these decisions.

Chairman EHLERS. At this time, I would like to introduce our witnesses. And we are fortunate to have an outstanding group of witnesses before us, broadly representative of the scientific and technical knowledge. I might mention we do not have anyone specifically from the environmental community. That will be dealt with at some other time, but we wanted to try and get the science and technology out first.

First of all, we have Dr. Thomas Burke, who is a Professor and Associate Chair of the Department of Health Policy and Management at the Johns Hopkins University Bloomberg School of Public Health. Dr. Burke served as a member of the National Academy of Sciences Committee on the toxicological effects of methylmercury. Second, we have Dr. David Krabbenhoft. He is a research hydrologist for the United States Geological Survey, better known by its acronym, USGS. I had a son who spent one summer working for

the USGS. Next, we have Dr. George Offen. He is the Senior Technical Leader of the Air Emission and Byproduct Management at the Electric Power Research Institute, which is the research arm of the utility industry, better known by its acronym, EPRI. And finally, Mr. Ken Colburn is the Executive Director of the Northeast States for Coordinated Air Use Management, an association of Northeast State Air Directors. As a Midwesterner, I can assure you that there is plenty of air in the Northeast. Previously, he served as New Hampshire's Air Director.

As our witnesses presumably have been informed, spoken testimony is limited to five minutes each. And in case you are not familiar with our system, we have the little timers, one here and one on your table. It will glow green for talk for the first four minutes, yellow for sum up for the next minute, and red for the stop sign. And so I ask for you to observe the stop signs. We may give traffic citations if you don't.

With that, after you have finished your testimony, Members of the Committee will each have five minutes to ask questions. And if there are a lot of questions, we may go an additional round.

We will start with Dr. Burke. Dr. Burke, you are recognized.

STATEMENT OF DR. THOMAS A. BURKE, PROFESSOR AND ASSOCIATE CHAIR, DEPARTMENT OF HEALTH POLICY AND MANAGEMENT, JOHNS HOPKINS UNIVERSITY, BLOOMBERG SCHOOL OF PUBLIC HEALTH

Dr. BURKE. I appreciate the opportunity to speak with you today. I am Tom Burke. I am a professor at the Johns Hopkins School of Public Health. I am epidemiologist and risk assessor, and I am also the Principal Investigator of the CDC Center for Excellence in Environmental Public Health Tracking, and I am currently working with about 20 states and major municipalities on issues of environmental exposure and public health outcomes. And I must say that mercury exposure and potential health impacts are a very important priority for the States. I am also a member of the National Academy of Sciences Board on Environmental Studies and Toxicology, and I currently co-chair the EPA National Pollution Prevention and Toxics Advisory Committee. Perhaps most importantly for today's meeting, I was a member of the—as you mentioned, the NAS panel that took a look at the toxicological effects of Methylmercury.

Before joining Hopkins, I served as a regulator and a health official. I was Deputy Commissioner of Health for the State of New Jersey and also Director of Science for the New Jersey DEP, so I participated firsthand in fishing advisories and some very difficult policy decisions.

My testimony today will focus on the questions that you have given to me.

First I wanted to give a very quick overview of what the Academy Panel found in our evaluation of the scientific basis for the EPA reference dose, which is really the starting point for the regulatory actions.

The charge to the Committee was to evaluate the scientific evidence, and we looked at a broad range of the available information, both from animal studies and from human studies, and really fo-

cused down on three major epidemiological studies. We met with the investigators to understand their methods and results and looked at and identified from this the most important, critical public health effects. We were concerned that mercury exposure effects different sub-populations differently and focused, to be most protective of public health, on the most vulnerable sub-population: unborn children. Therefore, we selected neurodevelopmental deficits as the most important, well-documented health effect.

The three studies we looked at, one in the Faroe Islands, one in New Zealand, and one in the Seychelles, were epidemiologic studies of maternal exposure and neurological development—maternal exposure to mercury and neurological development in children. Now two of these studies were positive, and the Seychelles study, at that time, did not show an association.

Based upon the public health principle of using a public health approach, we decided to use a positive study (they were all very well conducted) as the basis for our recommendations to EPA, the scientific basis for moving forward. We also conducted an analysis of population exposure here in the U.S. Now the large majority of Americans are at low-risk of adverse effects from mercury exposure, but as you mentioned, there is an important sub-population, high consumers of fish, that may, in fact, be at levels of concern. And we estimated that based upon women of child-bearing age and consumption patterns, there may be as many as 60,000 children born each year, not with adverse effects, but at elevated risk because of their mother's exposure.

Now a major question right now, particularly in light of the release of a new revision or an update of the Seychelles study, is—is the scientific basis for the National Academy of Science's conclusions—has that changed? We released our report in July of 2000, and since that time, there have been a number of new studies. Perhaps the most important is this longitudinal update on the Seychelles Island study, which continued to observe the children to age 9. The new study or the new update is, in fact, not a new study but a continued evaluation. And it must be recognized that it doesn't represent a new study but rather a refinement of ongoing surveillance.

The question has been raised: "If this data were available, would it have changed the weight of the evidence?" The latest data from the Seychelles study were not available at the time of the NRC report; however, the Committee did consider the possibility that updated results might confirm the previous negative findings at the Seychelles. In evaluating the overall weight of the evidence, we still felt that, with three well conducted studies, it was most appropriate to select a positive study, the Faroe study, as the basis for public health protection. Therefore, I feel, and I must say that I have discussed this with a number of my colleagues on the Committee, that the new update does not change the scientific basis for the Committee's conclusion.

A few other important studies you mentioned are the recently published result of the CDC look at exposure, where 8 percent of women were at levels of exposure of concern, have also confirmed our initial assessment of that small portion of the population that is at risk. And I might add at the time of our work, we were con-

cerned about potential implications on cardiovascular effects. There has been also new evidence there.

So to conclude, I would like to kind of sum up where the future direction should be. The update does not change the fundamental conclusions of the National Academy's report. There have been new studies. We are constantly reducing uncertainty and learning more. But as of this point, we still feel that there is a strong public health basis for the current EPA RFD, that this provides a sound and justifiable foundation for our efforts to protect public health. That being said, there are a number of important research issues that need to be undertaken, including getting a better idea of the exposure in this country, of the regional differences, identifying populations at high risk, and particularly, understanding the sources and levels of mercury contamination in our food supply. Finally, we need to better understand the interaction of mercury with other pollutants that we are exposed to, such as PCBs, to really get a better understanding of the long-term public health implications.

Thank you.

[The prepared statement of Dr. Burke follows:]

PREPARED STATEMENT OF THOMAS A. BURKE

Mr. Chairman and Members of the Subcommittee:

I thank you for the opportunity to testify today concerning the public health effects of mercury exposure. I am Dr. Thomas Burke, Professor and Associate Chair of the Department of Health Policy and Management at the Johns Hopkins Bloomberg School of Public Health, and I am founding Co-Director of the Hopkins Risk Sciences and Public Policy Institute. I am an epidemiologist and risk assessor and my major research interests focus on understanding and preventing the public health impacts of environmental exposures. I am also the Principal Investigator for the CDC Center of Excellence in Environmental Public Health Tracking at Johns Hopkins and am working with 20 states and major cities to improve our capacity to track hazards, exposures, and health effects that may be related to the environment. I am also a member of the National Academy of Sciences Board on Environmental Studies and Toxicology and serve as Co-Chair of the U.S. EPA National Pollution Prevention and Toxics Advisory Committee. Perhaps most relevant to today's hearing I served as a member of the National Research Council Committee on the Toxicological Effects of Methylmercury.

Prior to joining the faculty of Johns Hopkins I served as Deputy Commissioner of Health for the State of New Jersey and Director of Science and Research for the New Jersey Department of Environmental Protection. As a State official I was directly involved in the public policy decisions to protect the environment and public health, including many fish consumption advisories. I have a first hand appreciation for the difficult interface of science and policy in developing practical and protective approaches to public health and environmental regulation.

My testimony today will focus upon the questions that the Subcommittee has asked me to address.

What did the National Research Council panel find about the relationship between low-dose mercury exposure and adverse human health effects? Are subpopulations differentially affected by mercury exposure?

In response to a request from the Congress, the NRC established the Committee on the Health Effects of Methylmercury to evaluate the body of evidence that led to the EPA reference dose RfD (1). The charge also included evaluating newly available data that may not have been considered by the Agency, and consideration of sensitive subpopulations that may be impacted by consumption of contaminated fish. The Committee conducted and extensive review and weight of evidence evaluation of the available published literature on the health effects of mercury from both animal and human studies, and met with the investigators of major epidemiological studies to examine their methods and findings. Mercury exposure can cause a wide range of adverse effects throughout the life span and there are extensive data on effects on the developing brain.

Subpopulations may be differentially affected by mercury exposure. Therefore, to be protective of public health, the Committee focused upon the most vulnerable subpopulation, unborn children. We selected neurodevelopmental deficits as the most sensitive well documented effect, the critical effect for the derivation of an RfD.

The Committee carefully evaluated three large well designed epidemiological studies of the relationship between prenatal methylmercury exposure from maternal consumption of fish and subsequent neurodevelopmental deficits. In the Faroe Islands (2) and New Zealand (3) studies mercury exposure was associated with adverse neurodevelopmental outcomes. In the Seychelles (4) no relationship with adverse outcomes was observed. After considering the results of the three studies and the weight of the evidence the Committee concluded that a positive study provides the strongest public health basis for the development of public health and regulatory exposure guidance. The Faroe Island study was recommended as the critical study for the development of the RfD. Based upon the benchmark dose derived from this study, the Committee concluded that the EPA RfD of .1ug/kg per day is scientifically justifiable.

The Committee also conducted an analysis of population exposure levels and found that the large majority of Americans are at low risk of adverse effects, but some high fish consumers may be at risk of high mercury exposure. Based upon available fish consumption surveys for woman of childbearing age it was estimated that 60,000 children may be born each year with an elevated risk of adverse neurodevelopmental effects due to maternal mercury exposure.

To what extent have studies published since the panel issued its report in 2000 altered our knowledge about the health effects of mercury?

The NRC report was released in July of 2000. Since that time there have been a number of studies that have made important contributions to the body of knowledge concerning the public health impacts of mercury exposure. Perhaps the most notable is the recent longitudinal update of the Seychelles Island study (5) which reports on the continued observation of the cohort to 9 years of age. The results of the update reaffirm the earlier findings of no significant adverse neurological effects related to of *in utero* mercury exposure. The update provides important information on the Seychelles cohort as the children grow older. However it must be recognized that the findings do not represent a “new” study, but rather provide a refinement of the ongoing surveillance.

The question has been raised “If the Seychelles update were available to the NRC Committee would the recommendations have been different?” The latest data from the Seychelles study were not available at the time of the NRC report; however the Committee did consider the possibility that updated results might confirm previous negative findings. In evaluating the overall weight of the evidence of three well conducted studies, two positive and one negative, it was deemed appropriate to select a positive study as the basis for public health protection. I therefore feel that the recent report adds to our knowledge, but does not change the scientific basis for the Committee’s conclusions.

Other studies that have been published since the release of the NRC report have confirmed some of the findings and concerns of the Committee. CDC’s National Health and Nutrition Examination Survey found that eight percent of women of child bearing age had blood mercury levels that indicate exposures above the current RfD (6). This confirms the findings of the Committee’s margin of exposure analysis that found there is a small but important percentage of the population with exposures in the range of public health concern. In addition, a recent epidemiological study has found an association between mercury exposure (measured by toenail mercury concentration) and myocardial infarction (7). The need to better understand potential links between mercury exposure and cardiovascular disease and hypertension was among the research recommendations of the Committee.

What are the future research needs with respect to understanding the health effects of mercury?

There are a number of important continuing research needs if we are to improve our understanding of the public health impacts of mercury exposures in the U.S. population. The most fundamental need is to measure actual exposure levels in the population to identify those at highest risk, examine geographic differences, and improve our epidemiological surveillance to identify and prevent any related adverse health outcomes. Since there are fish consumption advisories throughout virtually all regions of the country, state health and environmental officials need improved tools to evaluate exposure and provide the public with better information about preventing exposures and health risks. Surveillance of mercury sources, exposures, and possible health related outcomes should be included in the developing CDC National

Environmental Public Health Tracking Network. Tracking can provide a foundation for U.S. based epidemiological investigations, guide the development of more effective regulatory strategies and enable us to measure our progress.

Better tracking of the mercury concentrations in fish and throughout the food supply is also needed. This will improve both our assessment and communication of mercury risks. Currently available information on important food sources is extremely limited. Consumers have little information resulting in enormous confusion and limiting the effectiveness of risk communication and prevention efforts.

Research is also needed to understand the potential impacts of mercury exposure throughout the life span. Little is known about possible long-term effects of exposure. This research should include examination of possible cardiovascular, reproductive, neurological, immunological and carcinogenic effects.

Research should also include evaluation of the health implications of interaction of mercury with other pollutants. For example, what are the health implications of cumulative exposures to mercury and persistent organic pollutants from dietary exposure? How do concurrent exposures to PCBs and other potential neurotoxic pollutants impact potential population health risks?

In conclusion, mercury is one of the most well studied environmental pollutants. Its potential harmful effects have been well documented in both human and animal studies. There is tremendous public concern about the potential adverse health effects of mercury, particularly regard the health and development of children. New studies have contributed important new insights, yet there remain a number of unanswered questions particularly concerning the full range of public health impacts from long-term low-level exposures. In the long-term the reduction of population exposures and management of mercury risks will depend upon our ability to recognize and reduce mercury emissions. In the meantime the current EPA RfD provides a sound and justifiable foundation for our efforts to protect the public's health.

Thank you very much for this opportunity to address the Subcommittee.

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Chairman EHLERS. Thank you.

Dr. Krabbenhoft.

STATEMENT OF DR. DAVID P. KRABBENHOFT, RESEARCH SCIENTIST, UNITED STATES GEOLOGICAL SURVEY

Dr. KRABBENHOFT. Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to present, on behalf of the U.S. Geological Survey, this statement regarding "Mercury Emissions: State of the Science and Technology."

Although humans have been using mercury in a variety of ways for the past 2,000 years, mercury has been cycling in the environment for a much longer period of time. Over the past 100 years, however, human activities related to industrialization and modernization have increased the amount of mercury cycling the environment and subsequent deposition to the landscape by a factor of about three to five over pre-industrial times.

The conversion process of inorganic mercury, which comprises the vast majority of mercury in the atmosphere, to methylmercury, known as methylation, has an overwhelming importance on the exposure of humans and wildlife and the environment. Were it not for methylation, bioaccumulation of mercury in the environment would only happen under extremely rare circumstances.

My testimony today seeks to describe a general understanding of the current state of science regarding mercury transport fate in the environment. While constructing this testimony, I have focused on the four questions your Subcommittee has asked of me.

Question one: "What do we know about how mercury reacts in the atmosphere and what determines its deposition, and to what extent is deposition local, regional, or global?" The amount of mercury contributed from each of these geographic source types at any particular location can range widely. In truly remote settings where equally high levels of mercury in food webs can occur, contributions from global mercury sources likely dominate, whereas in settings near emission sources, the local contributions are likely more important.

One critical scientific advance of researchers over the past decade has been the ability to discriminate the three principle forms of mercury in the atmosphere, and those are: reactive gaseous mercury; gaseous elemental mercury; and particulate mercury. Although greater than 95 percent of the mercury in the atmosphere is gaseous elemental mercury, what deposits onto the landscape are the other two forms of mercury. As such, understanding the processes that regulate the transformation of these forms of mercury is critical for being able to predict where mercury from a particular source will deposit.

Question two: "What do we know about the relative reactivity of old versus new mercury and anthropogenic versus natural mercury?" Mercury is an element, and as such, all mercury is "natural." However, its reactivity and mobility is controlled by the details of its chemical form, and several of man's activities serve to change its chemical form. For example, mercury in coal is largely found as traces in the mineral pyrite, which is relatively stable if left undisturbed. However, upon combustion, much of the mercury in the coal is reduced to the gaseous elemental mercury state, thereby increasing its post-emission transport distance and reactivity.

Recently, researchers have begun to address the question of old versus new mercury in the environment. The terms "new" and "old" do not refer to sources, but rather how long that mercury has been in the environment. Results thus far have clearly shown that experimentally administered new mercury is much more apt to become methylated and incorporated into the food web than old mer-

cury probably because of physical and chemical differences in these two mercury pools.

Question three: “What does research tell us about the extent to which reducing mercury emission deposition will reduce mercury levels in fish?” Past studies at point source contaminated sites in areas where atmospheric deposition has declined tell us that fish mercury levels generally follow mercury-loading rates. The timing in the recovery, however, can vary substantially from years to decades. The extent of the recovery will likely be proportional to the fraction of the deposition rate at any specific location that is eliminated.

Lastly, question four: “What are the future research needs with respect to understanding how mercury cycles in the environment?” First, research to improve our understanding of chemical forms of mercury from emission sources, changes that occur after release and during transport, and controls on deposition patterns. Second, research to help refined estimates of the relative contributions of both natural and anthropogenic mercury emissions. Third, research to improve our understanding of what factors control the far-ranging observed differences among ecosystem types in terms of their sensitivity to mercury loading and what non-source control strategies can man consider to reduce methylmercury production and exposure. Lastly, research to help develop an understanding of the mercury sources and sites of methylation that are responsible for high levels of mercury in marine food webs. The vast majority of mercury research over the past 15 years has been done on freshwater ecosystems, but few insights can be transferred from those freshwater systems to the marine environment from which most consumed fish are harvested.

Mr. Chairman, this concludes my remarks, and I would be happy to respond to questions by Members of the Subcommittee.

[The prepared statement of Dr. Krabbenhoft follows:]

PREPARED STATEMENT OF DAVID P. KRABBENHOFT

Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to present, on behalf of the U.S. Geological Survey, this statement regarding “Mercury Emissions: State of the Science and Technology.” This statement seeks to describe a general understanding of the current state of science regarding mercury transport and fate in the environment, focusing on the four questions posed by the Subcommittee.

Background

Although humans have been using mercury in a variety of applications for more than 2000 years, mercury has been cycling in the environment for a much longer time through natural occurrences such as volcano eruptions. Over about the past 100 years, however, human activities related to industrialization and modernization have increased substantially the amount of mercury released to the environment, particularly via atmospheric emissions. Most researchers have concluded that rates of atmospheric deposition of mercury on average are about 3–5 times greater presently than in historic times. Once deposited on oceans, land or freshwater systems, a portion of the mercury re-emits back to the atmosphere. As a result of the mercury re-emission process, fluxes from land and oceans to the atmosphere are now about three times higher than pre-industrial periods, and mercury contributions from these “natural sources” constitute about two thirds of the mercury emissions presently. Although these re-emissions come via “natural sources,” the increased amount of mercury cycling in the environment is driven by the increased amount of mercury introduced from human sources.

The overall increase in the amount of mercury cycling in the environment has resulted in exacerbated mercury exposure to food webs, including humans, and the

widespread awareness of these levels has led to consumption advisories for elevated levels of mercury in fish. Concerns about environmental mercury pollution and contamination of aquatic food webs stem largely from the human health risks of dietary exposure to methylmercury, the dominant form of mercury in the edible flesh of fish and aquatic mammals, and the form of mercury that is the focus of most environmental studies today.

The widespread geographic extent and adverse consequences of methylmercury pollution continue to prompt considerable scientific investigation. The conversion of inorganic mercury, the form comprising the vast majority of mercury in the atmosphere, to methylmercury (methylation) results from a series of very complex, processes that are facilitated by naturally occurring bacteria. Scientists now understand that the methylation process primarily occurs in anaerobic (oxygen free) sediments in aquatic ecosystems. In addition, we know that the methylation process involves the intersection of the environmental sulfur cycle with the environmental mercury cycle. The end result of these complex processes is a net increase in the overall toxicity of mercury, such that if mercury were not methylated in the environment, it likely would only reach levels of toxicological concern in rare instances.

1. What do we know about how mercury reacts in the atmosphere and what determines its deposition? To what extent is deposition local, regional or global?

Although there is general agreement that atmospheric mercury emissions and transport pathways are the phenomenon that are chiefly responsible for the widespread mercury contamination, particularly for remote and semi-remote areas, scientific understanding of the processes controlling the region of influence of a specific emission source is still an active area for research. Establishing the region of influence for various mercury emission sources has been evaluated through several means, including: intensive site-specific monitoring, numerical modeling, and historical reconstruction of anthropogenic effects through dated cores of sediment and ice. Together, all these scientific approaches have yielded considerable improved understanding of the relationships between atmospheric mercury sources and deposition areas, but it should be stressed that this is still an area of evolving understanding.

One of the critical scientific advances of researchers over the past decade has been the ability to discriminate the three principal forms of mercury that exist in the atmosphere:

- particulate mercury associated with settling particles,
- reactive gaseous mercury (RGM), and
- gaseous elemental mercury.

These three forms largely are determined by the chemical species (speciation) in which the mercury exists, that is, whether it is in a neutral, uncharged state as in gaseous elemental mercury, or in a charged state. Mercury in the atmosphere is largely (>95 percent) gaseous elemental mercury, although most of what deposits is composed of the other two forms of mercury (particulate and RGM). Particulate and reactive gaseous mercury have relatively short travel distances (up to tens of kilometers) and small residence times in the atmosphere, whereas gaseous elemental mercury exhibits global-scale transport and has an average atmospheric residence time of about one year. As such, understanding what controls the transformation from gaseous elemental mercury to particulate or RGM, is critical for being able to predict where mercury will deposit from an emission source.

Presently, scientists believe that mercury depositing in remote settings, at long distances from substantial sources, is derived from the transformation in the atmosphere of gaseous elemental mercury by ozone and possibly several other atmospheric oxidants. On the other hand, mercury deposited near emission sources is likely to be released as particulate mercury or RGM. Atmospheric emission sources, especially those related to human activities, have extremely variable amounts of the three forms of mercury, and as such the region of influence of a specific emission source can be quite variable and difficult to predict in the absence of source-specific measurements. Scientists have been able to match deposition patterns measured on the ground using mercury speciation measurements at a limited number of combustion sources and numerical models that simulate post emission oxidation reactions. This lends credence to many of the assumed important factors controlling source-receptor relationships for mercury.

Reliable records of temporal trends in mercury deposition at a specific site also can be useful for evaluating mercury sources through time. Temporal trends in mercury deposition can be obtained by using dated sediment and/or glacial ice cores, where a variety of scientific tools are used to establish the age of various horizons

in the core, for which a mercury concentration can be measured. Sediments from lakes, reservoirs, and bogs have been used in the past for historical reconstructions of mercury deposition. These historical reconstruction efforts have proven to be useful for evaluating local-to-global mercury sources. Scientists using this approach have successfully documented changes to mercury deposition from natural and human-related mercury emissions over thousands of years, and illustrated that mercury contributions at any particular location can range from local to global, and the source attribution can change dramatically over time.

In remote and semi-remote areas of North America that lack local sources of anthropogenic mercury, the rate of mercury accumulation in many lake sediments has increased by a factor of 2 to 4 since the mid-1800s or early 1900s. Dated ice cores are also a useful means to infer mercury deposition, albeit at high altitudes or in very remote polar settings. An ice core from the Fremont Glacier, Wyoming, demonstrated several key findings. It illustrated how variable mercury deposition can be at any particular location through time, and how various mercury sources can dominate a depositional period. For this specific location in Wyoming, the ice core revealed that:

(1) mercury deposition rates after industrialization have ranged has a high as 20 times greater than pre-industrial periods;

(2) at times, volcanic eruptions located in the northern and southern hemisphere have resulted in recognizable, short-lived, periods of high mercury deposition;

(3) upwind regional uses, such as the California Gold Rush, are clearly observed; and

(4) about 70 percent of the mercury deposited in this location over the 270 year time period recorded by the ice core is attributed to global human activities.

Ascertaining the local, regional, or global mercury source contributions to any particular location is difficult. At any location, the amount contributed from each of these three geographic source types could range widely. In truly remote settings, the contributions of mercury from globally distributed sources will likely be more important; whereas, in settings nearer emission sources the local contributions will likely predominate. Future abilities to predict the fractions from these sources will rely on improved understanding of mercury speciation at various sources, transport processes and reactions, and deposition processes.

2. What do we know about the relative reactivity of old vs. new mercury and anthropogenic vs. natural mercury?

Unlike many other high-visibility environmental pollutant problems, mercury is an element, and as such, all mercury originated as "natural" mercury. The reactivity and mobility of mercury is controlled by the details of its chemical form (speciation) in the environment. It is in affecting this chemical form that man has had the greatest impact. For example, the principal ore of mercury is the mineral Cinnabar, which is relatively insoluble and stable, and was used as a red pigment long before the process for refining mercury ore to recover elemental mercury was discovered. Converting cinnabar to liquid elemental mercury, which was the specific conversion process of placer miners during the Gold Rush, greatly increases its propensity to vaporize to the atmosphere. Similarly, most of the mercury found in coal deposits is found as traces in the mineral pyrite, which is also relatively stable if left undisturbed. However, upon combustion a substantial amount of the mercury in coal is converted to gaseous elemental mercury, and thereby increasing its post emission transport distance.

There are important natural processes that also serve to increase the reactivity of mercury, regardless of whether it originates from natural or anthropogenic sources. For example, researchers recently discovered that natural processes lead to formation of high levels of bromine near the surface of the Arctic and Antarctic regions at the time of the first sunrise, following the extended dark, polar winter. This process serves to oxidize (chemically change) large quantities of gaseous elemental mercury in the atmosphere over the polar regions, thereby converting it to particulate or reactive gaseous mercury and substantially increasing the deposition rate of a highly reactive form of mercury to the landscape there. In summary, there are no known differences between the chemical reactivity of mercury from anthropogenic or natural sources, but what does matter is what controls or alters the chemical form of the mercury.

Recently, researchers have begun to investigate whether there is any difference between "new" versus "old" mercury in the environment. The terms "new" and "old" do not refer to the source, but simply how long the mercury has been deposited on

the landscape. This question has been posed because of vast pools of mercury that currently reside in soils and sediments from over a century of enhanced mercury deposition. Scientists wondered if this relic mercury pool might not sustain the present mercury problem for very long periods of time.

In order to address this question, scientists have initiated dosing studies, in which mercury is delivered to test sites ranging in size from about a cubic meter, to whole watershed scale. When conducting these studies, scientists are using traceable forms of mercury that behave the same as the existing mercury, but that are distinguishable using advanced analytical procedures. This experimental approach has been applied thus far in two distinctly different ecosystems: the Everglades of Florida, and a boreal forest ecosystem in western Ontario. Results from these two studies have shown remarkable agreement in many ways, despite their different ecological settings. First, the results have clearly shown that the experimentally administered mercury ("new mercury") is much more apt to become methylated (about 5 to 10 fold) than previously existing "old mercury." The precise physical and/or chemical reasons for these observations are still being researched, but at this point we do not have a definitive explanation.

3. What does research tell us about the extent to which reducing mercury deposition will reduce mercury levels in fish?

Recent and historic research results tell us that fish mercury levels generally follow changes in mercury loading rates, both for increasing and decreasing rates. The timing of the recovery, however, can vary substantially, and in some cases can take many decades. For example, at industrially polluted Clay Lake, Ontario, mercury concentrations in fish have declined from peak levels but remained substantially above the Canadian mercury advisory level (0.5 mg/g) nearly three decades after operations ceased at a nearby chlor-alkali plant source. Mercury concentrations in fish from Clay Lake decreased rapidly after the plant ceased operations—from about 15 micrograms per gram wet weight in 1970 to about 7.5 micrograms per gram in 1972—and then declined gradually to about 3.5 micrograms per gram in 1983. However, concentrations apparently declined little during the next 15 years (mercury in fish tissues averaged 2.7 micrograms per gram in a sample of 14 walleyes taken from Clay Lake in 1997 and 1998). It should be noted however, that the cause of persistent problems with methylmercury contamination of aquatic biota at historically contaminated sites may result from:

- continuing, unintended emissions of mercury from the local point source,
- recycling and methylation of the mercury present in contaminated sediments,
- temporal increases in the reactivity of mercury from highly contaminated zones,
- current atmospheric deposition of mercury from other sources, or from a combination of these factors.

More recently, researchers conducting mercury-loading studies have observed that there is a direct relationship between the amount of mercury added to an ecosystem, and the amount that is observed in fish. The time frame for a response depends on the ecosystem in which the study was conducted. In the Everglades, the response was very fast (within the season of the experiment or about 30–90 days). In a deeper, colder lake in Canada, the response was about a year, but the magnitude of the response there was still growing after two years. Although it stands to reason that the reverse observation would also be true (that reduced levels of loading would lead to lower levels in fish), researchers need more time to monitor the experimental sites when they transition from mercury loading studies to mercury reduction or recovery studies.

4. What are the future research needs with respect to understanding how mercury cycles in the environment?

There are several areas of research needed to reduce the uncertainties relating the linkages between mercury sources, cycling in the environment, and bioaccumulation in fish.

- Although scientists have made substantial advances in our understanding of the importance of detailed information on the chemical form of mercury in the environment and important chemical reactions, an incomplete understanding still exits. At the present time, relatively few detailed studies of atmospheric mercury transport have been conducted near specific sources, such as: combustion facilities, urban settings, or near known natural mercury sources. Without this information, it is difficult to predict how much mercury in a particular location is derived from local, regional, or global sources.

- Better definition of the relative contributions of natural versus anthropogenic sources. Current estimates of mercury emissions from these two broadly defined source categories range substantially, and presently hinder our ability to anticipate the level of benefit that might be derived from proposed emission reductions. Natural mercury source emissions are particularly poorly understood.
- Better understanding of what factors control the observed far-ranging differences among ecosystem types, in terms of sensitivity to mercury loading and bioaccumulation. The literature holds that some ecosystems are very sensitive to mercury inputs and can yield substantial levels of methylmercury, while others are not. A better understanding of what controls this sensitivity to mercury inputs and production of methylmercury will greatly aid our ability to predict the level and timing of potential benefits received from changes to mercury loads.
- At the present time, very little understanding from the scientific literature can be derived for resolving where marine fish get their mercury. This is particularly important in light of the fact that most of the fish consumed in the United States and elsewhere are marine fish, yet a preponderance of the literature is based on freshwater studies. It is difficult to use the conceptual models developed for shallow, freshwater systems and apply them to deep, oceanic settings. Integrated, multi-disciplinary studies that link terrestrial mercury sources, near-coastal and estuarine cycling, and bioaccumulation of mercury in important commercial and sport fish are needed.
- Lastly, questions that require additional attention to ensure effective environmental protection are: how and to what extent will decreases in anthropogenic mercury emissions decrease the amount of mercury cycling in the environment, in what magnitude will those decreases reduce mercury bioaccumulation in aquatic ecosystems, and what will be the timing of such a recovery.

Mr. Chairman, this concludes my remarks. I would be happy to respond to questions Members of the Subcommittee may have.

Chairman EHLERS. Thank you.
Dr. Offen.

STATEMENT OF DR. GEORGE R. OFFEN, SENIOR TECHNICAL LEADER, AIR EMISSION AND BYPRODUCT MANAGEMENT, ELECTRIC POWER RESEARCH INSTITUTE

Dr. OFFEN. Thank you, Chairman Ehlers, for the opportunity to speak before you on the important subject of mercury control. You have kindly introduced EPRI so I don't need to do that except to mention that we do, in our work, collaborate quite a bit with suppliers, equipment suppliers, and government agencies. And particularly in the case of mercury, we have strong collaborations with the Department of Energy and the EPA.

In that area, you asked us to talk about five questions in three areas. The first one is on existing controls and what mercury reductions can one expect from those controls. On the average in the U.S., current power plants with their emission controls for particulates, NO_X, and SO_2 are achieving a 40 percent reduction. However, that varies from 10 percent at some power plants to 90 percent at other power plants. And we see the primary differences being a function of the coal that is burned and the air pollution controls that are already in place at those power plants. Furthermore, those numbers are actually what we call snapshots in time. They are derived from three tests taken for two-hour periods, and we do know that mercury emissions vary widely over time. Over a week's period, they can vary by a factor of five to one, even when the same coal is burned.

There is, beyond the 40 percent number I mentioned, a fraction of the coal, particularly a portion of the eastern bituminous coal,

that is washed, and the washing process is used for removing ash and sulfur. And that process also does remove some mercury, on the average 25 to 35 percent.

You asked what determines the effectiveness of the mercury reductions, and I have, more or less, answered that. The coal, and especially the chlorine content and its reactivity, its ability to burn completely, and, of course, the air pollution control devices. And the reason these two relate is that mercury, as Dr. Krabbenhoft mentioned, is released in two different gaseous forms. Any mercury that is particulate is captured by the particulate control. But it can be, as he said, either an elemental mercury or an oxidized form when it is combined with other chemicals. And the other pollution controls, like particulate and SO_2 controls, really capture the oxidized fraction and not the elemental fraction.

You asked about controls that are under development today. The industry, and that includes EPRI, the suppliers, the power industry themselves, DOE, EPA, are really following four parallel paths on that. One is to try to better understand the interactions between selective catalytic reduction for NO_X control and scrubbers for SO_2 control with regard to the mercury impact, what is called the co-benefits in all of the discussions that you have had. We see it in some cases and don't see it in some cases.

The next area is the area of sorbent injection, which is the technology where you blow a dust, a material like activated carbon, into the gas and that absorbs the mercury, and then the activated carbon with the mercury is captured by the particulate control. We are doing quite a bit of work in that area as industry. That seems to be the nearest-term mercury-specific control that is on people's agenda. We are trying to reduce the costs. We are trying to develop sorbents that are more effective for more different coals. The—and also trying to understand what the negative impacts may be and mitigating those and overcoming those.

The third area is to develop and demonstrate new technologies. These are falling into a couple of categories. One, again, is to help capture mercury and scrubbers, so we are looking at catalysts that will make more oxidized mercury. We are looking at chemical addition to boilers that will make more oxidized mercury. And the other is trying materials that you can put in the very back end of your power plant that sit there and that capture mercury and that you occasionally regenerate, pull out and regenerate.

And then finally, we are looking at multi-pollutant controls and seeing what role they could play in the picture of mercury.

You asked about the inferences of the full-scale tests of these controls on what we know about effectiveness and cost. I need to mention that the only full-scale tests that have been done today have been short-term, about one week. Each test has been on a different fuel. And you have a figure in your package that shows the removal is a function of the amount of carbon that is injected. And you will see a separate line for each test that has been done. Again, one test for each fuel. We don't know if those lines are representative of each of those fuels or whether they are unique situations. They are also short-term, so we don't have any sense of what the long-term impact might be.

Fortunately, this is where the DOE is stepping up to the plate right now. They have just released eight contracts that will be testing all of these technologies or many of these technologies for multiple month periods, one- or two-month periods, so we should have a better handle on that after the tests are done. That will be in the '04, '05, and possibly '06 time frame.

With that said, just to give you a flavor of the numbers, we are seeing right now on these, with the caveats, 60 to 70 percent capture with sorbent injection in plants firing Powder River Basin coal, which is now used by about 40 percent of the plants, and going up to 90 percent in the low-sulfur eastern bituminous case, which is the one case we are getting that much reduction. As I mentioned, we don't understand the sustainability and long-term impacts of that. So we are very much looking forward to and very supportive of the DOE program to extend our tests and our knowledge on that base.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Offen follows:]

PREPARED STATEMENT OF GEORGE R. OFFEN

Mr. Chairman and Members of the Subcommittee:

Thank you for inviting EPRI to address the House Committee on Science's Subcommittee on Environment, Technology, and Standards on the important subject of mercury reductions from power plants. I am George Offen, and I manage our programs in air emission reductions and the beneficial use of combustion products. EPRI was established 30 years ago as a non-profit, collaborative R&D organization to carry out electricity-related supply, delivery, end-use, and environmental R&D in the public interest. Our funders include electric power companies responsible for over 90 percent of the electricity sold in the U.S., as well as over 60 companies worldwide. We also cooperate closely with (and for some projects receive funding from) government agencies in our research programs, particularly DOE and EPA, as well as equipment suppliers and engineering firms. This is especially true in the case of mercury.

For well over a decade, EPRI has been conducting research on all aspects of mercury sources, movement and chemical transformation in the environment, health effects, and methods to reduce emissions. My remarks today will respond to five questions in three topical areas that this subcommittee asked EPRI to address on the subject of mercury control technologies.

1. Existing controls

A. To what extent do control technologies in use today at utilities reduce mercury pollution?

On average across the domestic coal-fired population of power plants, current technologies used to reduce particulate, NO_X and SO_2 emissions capture about 40 percent of the mercury that enters these boilers with the coal. However, these removals vary from less than 10 percent to over 90 percent, depending on the coal and air pollution controls used. Further, the data that underlie these generalizations are snapshots in time at each plant in many cases just a few tests over a 1–2 day period—while we now know that emissions can vary by a factor of five or more over a week's period. I should note that the removal efficiencies cited above are additive to the mercury removed by coal washing for the many supplies of eastern bituminous coal that are washed; cleaning these coals often provides an average mercury reduction of 25–35 percent before the coal arrives at the power plant.

B. What determines the effectiveness of these technologies in reducing mercury emissions?

The primary factors that affect the capture of mercury by existing air pollution controls are the coal burned and the type of air pollution (NO_X, SO_2, particulate) controls used at the plant. Mercury in the flue gas appears as a mix of elemental (or metallic, non-water soluble) and oxidized (water soluble) mercury, depending pri-

marily on the coal and to a lesser extent on the design of the boiler. Some controls, such as scrubbers for SO_2 reduction, capture only oxidized mercury. In some cases, selective catalytic reduction (SCR) for NO_X control may increase the percent of the mercury that is in the oxidized form, enabling a downstream scrubber (if present at the power plant) to capture more of the mercury. Coals and boilers that result in increased levels of carbon leaving the boiler unburned tend to produce a fly ash that may adsorb some of the mercury. The amount that would be adsorbed and subsequently captured by the particulate control depends on the technology used—electrostatic precipitators or baghouses—due to the difference in how the fly ash and flue gases contact each other in these devices. All these interactions depend on complex chemical reactions between various species in the flue gas, especially chlorine, but we do not yet totally understand this chemistry.

2. New controls

A. What are the major technologies under development today to control mercury emissions from power plants?

The technical community is following four parallel paths to seek cost-effective, sustainable mercury controls for the domestic boiler population—(1) trying to understand and improve the performance of existing controls, especially the combination of SCR and scrubbers; (2) developing and lowering the cost of sorbent injection (such as activated carbon), the nearest-term mercury-specific technology; (3) developing and demonstrating new technologies; and (4) developing multi-pollutant controls to capture NO_X, SO_2, mercury, and particulate in an integrated fashion. With sorbent injection, a powder such as activated carbon is injected into the flue gas ahead of the particulate collector, where it captures the mercury by adsorption and is then, itself, collected along with the fly ash in the particulate collector. The technical community is looking at variants of this process aimed at reducing costs, avoiding contamination of the ash by using non-carbon sorbents, and developing sorbents that work for all coals and particulate/SO_2 controls. New technologies include catalysts designed specifically to oxidize mercury that would be placed at the clean end of the particulate collector for plants with downstream SO_2 control; attempts to make flue gas from Powder River Basin and other low-chlorine western coals behave like Eastern bituminous coal by adding chemicals to the coal or boiler; and fixed structures that sit in the flue gas ducts and adsorb mercury until they need to be regenerated.

B. What do full-scale demonstrations tell us about the likely costs and effectiveness of these technologies?

To date we only have full-scale data on activated carbon injection, and those data are limited to one week tests at just one site for each of the coals tested. Mercury removals were different at each of the sites (see Figure, which also shows the broad range of pilot-scale results), and we do not know if this was due to the different fuels or other reasons. The short-term removals ranged from a maximum of 60–70 percent at the site burning Powder River Basin coal to as much as 90 percent at the plant firing Eastern low-sulfur bituminous coal site. Because these tests were demonstrations, we do not have commercial cost data for the installations. Furthermore, having no long-term operational experience with these systems, we know neither their ability to sustain these levels of performance nor their potential impacts on plant operations and maintenance. Assuming sustainable operation and no unexpected impacts—both big assumptions at this point in time—we have estimated costs of $2 MWh to $3 MWh for activated carbon injection, including sorbent, operation and maintenance, and amortized capital.

3. What are the major barriers to development of technologies to control mercury emissions from power plants?

The biggest barrier is the complexity of mercury chemistry in flue gases, and the underlying lack of fundamental data on the chemical reactions in this kind of environment. This prevents us from (1) extrapolating tests on one power plant to other plants with apparently similar features, and (2) carrying out most of the development of new technologies in the lab, where the costs should be less and turnaround time quicker. Consequently, most of our development work occurs via full-scale trials at power plants, and we need data from enough plants to allow us to develop correlations we can use to predict mercury control performance across the population of U.S. boilers. The other main barrier is the absence of any long-term experience with mercury controls to address the questions I have raised on sustainable operation and potential impacts on boiler operation and maintenance.

DOE's Phase II field test program, which EPRI strongly supports, is an important step to address both these needs. We believe that additional tests, possibly of shorter duration, are still needed to provide greater confidence in the representativeness of the data we will obtain under the DOE Phase 11 program, and they are needed on an accelerated schedule so that the power companies can use the results to meet their upcoming regulatory obligations. We would also recommend that DOE conduct similar field test evaluations of integrated pollution controls for those that show promise at smaller scale.

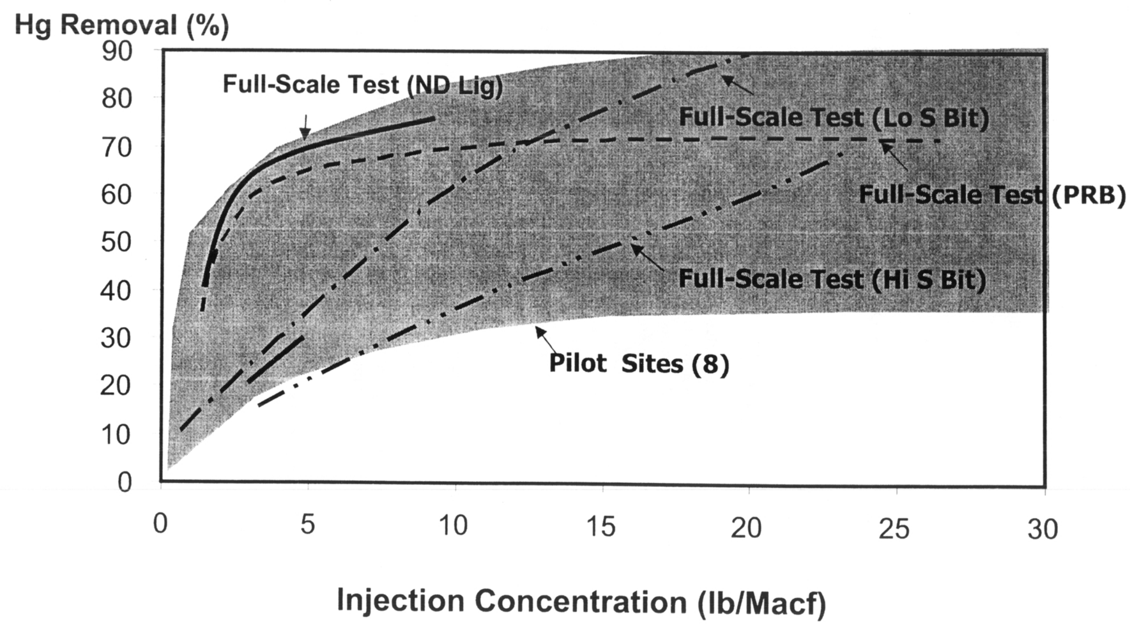
Summary

Over the past decade, the technical community has made substantial progress in understanding mercury emissions and developing mercury reduction options for a wide range of coals and power plant air pollution control configurations. Coal washing and existing emission controls already reduce some of the mercury emitted from coal-fired power plants, although this varies widely. The ability to remove mercury from power plant flue gas is determined largely by the coal properties—especially chlorine content and coal reactivity—the degree to which the boiler can combust the coal completely, and the controls in existence at each individual plant. Correspondingly, suppliers, DOE, EPRI, and others are developing a variety of mercury controls to provide cost-effective solutions for these various fuel/equipment configurations. Accelerated research on mercury flue gas chemistry in parallel with expansion of the current DOE field test program are needed to determine performance and cost with confidence.

Thank you, again, for giving EPRI the opportunity to provide these comments.

Field Results – ACI Hg Removal w/ ESPs

-Which line is correct?
-Is each unique or representative of a category?



STATEMENT OF MR. KENNETH A. COLBURN, EXECUTIVE DIRECTOR, NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT

Mr. COLBURN. Thank you, Mr. Chairman.

NESCAUM appreciates the chance to address the Subcommittee regarding the technological feasibility of controlling mercury from power plants. Your timing is particularly opportune, as NESCAUM has just completed a major report on mercury and control technologies to reduce its emissions.

Concern over the adverse health impacts of mercury has led the Northeast States to adopt aggressive mercury-reduction initiatives. In 1998, the New England States set a goal of reducing mercury to 50 percent by 2003, 75 percent by 2010, and then to virtually eliminate mercury emissions over time after that. We have met the 2003 goal with a reduction of 55 percent.

We did this by conducting a careful scientific analysis of our mercury sources and the technological feasibility of controlling their emissions. This study allowed states to adopt standards mainly for municipal waste combustors, in most states the largest sources, that were almost three times more stringent than federal standards. Our 75 percent goal will require equally aggressive controls on the part of power plants. And several states have already moved to implement stringent mercury limits on power plants. Due to deposition, however, a strong national program through the mercury MACT is crucial to our ability to protect the public.

This afternoon, I would like to comment just briefly on mercury controls currently in use at power plants, emerging mercury-specific control technologies, and barriers to deploying those controls all in the context of EPA's mercury MACT proposal.

Under the Act, MACT can not be less stringent than the average achieved by the best performing 12 percent of power plants for which EPA has information. This is known as the "MACT floor." And based on EPA's current data, that would be a 91 percent reduction in mercury found in the coal. At present, mercury reductions from power plants are mostly co-benefits, as Dr. Offen mentioned, resulting from controls for other pollutants, such as NO_X and sulfur dioxide in particular.

Nearly all coal-fired power plants have at least some air pollution control devices, and a number of them already achieve impressive mercury reductions. In EPA's tests, for example, four bituminous plants caught 95 percent of the mercury in the coal. And some subbituminous plants captured 74 to 86 percent of the mercury in the coal. While these co-benefits are substantial, they don't include any attempt to optimize the controls for mercury removal. Remember, they are for other pollutants. So the potential exists for even greater mercury reductions from existing controls.

Many new mercury-specific control technologies are also well on their way to commercialization. Activated carbon injection, for example, is being successfully demonstrated in full-scale applications, showing that a 90 percent reduction is feasible for power plants at costs comparable to those for NO_X reductions. A recent American Coal Council article, for example, said that activated carbon injection "requires minimal new capital equipment, can be retrofit without long outages, and is effective on both bituminous and subbitu-

minous coals," and thus, "it appears unlikely that compliance with pending mercury reduction regulations will result in significant fuel switching." Recognizing this, a permit issued in June 2003 for a new power plant in Iowa burning western subbituminous coal requires mercury reductions of over 80 percent using activated carbon injection.

Other promising technologies include enhanced wet scrubbing to help with oxidization of the mercury, as Dr. Offen mentioned, K-Fuel (r), a processed coal, and Powerspan's Electrocatalytic Oxidation technology. I will hopefully have more time to go into these during the question and answer session.

While these mercury-specific technologies are closest to commercialization, the Subcommittee should also be aware that several additional mercury control technologies have also emerged from the laboratory and are now being tested. These include EPRI's "Toxicon" process, the use of flyash as a sorbent at GE Power Systems and CONSOL Energy, promising chemical versus the usual physical sorbents at Amended Silicates, and various metal amalgamation approaches. The fact that several of these approaches were not even in existence when we looked at technologies two and three years ago illustrates the technology creation benefits that even the prospect of a good mercury MACT rule is having.

The only real barrier to controlling mercury emissions from power plants is the current absence of a regulatory driver to create a market for mercury control technologies. Coal-fired power plants are not installing aggressive mercury-specific control technologies today not because they can't, but because there is simply no requirement for them to do so.

In September of 2000, NESCAUM issued a report that looked at a history of sulfur dioxide controls, NO_X controls, and auto emissions, and we found that regulations with well defined targets and compliance deadlines drive innovation and control technology, resulting in dramatically lower implementation costs than initially anticipated.

In short, we need to expose the commercial availability argument for the red herring that it is. And I would caution the Committee that there are several other red herrings in the wings, those being: the technologies don't work all of the time, the cost is too high, and they can't be installed in time. We all had those with sulfur and nitrogen controls as well. History shows that market forces will capably address each of these concerns. Technology rapidly gets the kinks out and becomes reliable. Costs drop dramatically, and the market gets the job done on time. But it won't happen until there is a market, and there won't be a market until there is a regulatory driver, the mercury MACT rule.

In conclusion, one of my favorite sayings is: "Ask an engineer to do something and you get nothing but problems. Tell an engineer to do something and you get nothing but solutions." Today, we are getting significant mercury reductions as co-benefits from non-optimized controls for other pollutants. We have full-scale tests on new, cost-effective control technologies that reduce mercury substantially from a variety of coals. And we have new, even more promising mercury control technologies coming out of the labs. Let us tell our power sector engineers that it is time to reduce mercury

emissions by 90 percent and begin to reap the public health and environmental technology benefits that the resulting market will bring forth.

Thank you.

[The prepared statement of Mr. Colburn follows:]

PREPARED STATEMENT OF KENNETH A. COLBURN

Thank you Mr. Chairman. My name is Ken Colburn. I am the Executive Director of the Northeast States for Coordinated Air Use Management (NESCAUM). NESCAUM is an association of state air pollution control agencies representing Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont. We provide technical assistance and policy guidance to our member states on regional air pollution issues of concern to the Northeast. On behalf of our eight member states, I would like to express our appreciation for this opportunity to address the Committee regarding the technological feasibility of controlling mercury from electric generating facilities. The timing is particularly opportune, as NESCAUM has just completed a thorough review and assessment of mercury emissions from power plants and control technologies to reduce these emissions.[1] This report, *Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action,* has been made available to the Subcommittee.

Concern over the adverse public health impacts associated with exposure to methylmercury has prompted all of the Northeast states to issue fish consumption advisories and to adopt and implement aggressive mercury reduction initiatives. In 1998, the New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted a regional Mercury Action Plan that established a science-based, integrated regional strategy intended to reduce in-region emissions by: 50 percent by 2003; 75 percent in 2010; and virtually eliminate anthropogenic releases over the long-term. As of 2003, the region has achieved a 55 percent reduction in mercury emissions.

The success of the NEG/ECP effort is largely a function of the fact that the states and provinces conducted a careful analysis of the sources of mercury emissions in our region and technological feasibility of measures available to control these emissions. For example, based on our technology assessment, states where able to adopt standards for municipal waste combustors (MWCs)—the largest source of mercury in many Northeast States—nearly three times more stringent than the federal standards, and MWCs have routinely achieved compliance with even the most stringent state standards. Achieving our next goal of a 75 percent reduction will require equally aggressive controls on power plants which are now the largest source of mercury emissions in the region. To address this need, several states in the Northeast have already moved to include stringent mercury emission limits as part of multi-pollutant requirements for power plants. However, since about one-third of the mercury deposition in the Northeast is attributable to out-of-region sources, primarily power plants, a strong national mercury MACT standard is critical to our ability to protect the public from the harmful health effects associated with exposure to methylmercury.

In my testimony this afternoon, I will: (1) provide an overview of in-use mercury pollution control technology for power plants; (2) discuss emerging mercury-specific control technologies; and (3) consider barriers to the development and deployment of mercury emission controls for power plants. Given the pending proposal of a Maximum Achievable Control Technology (MACT) standard by the U.S. Environmental Protection Agency (USEPA), I will relate my comments on technological feasibility to that process.

In-Use "Co-Benefit" Mercury Control Technologies

For existing sources, MACT cannot be less stringent than the average emission limitation achieved by the best performing 12 percent of the existing sources for which the Administrator has emissions information. This is known as the "MACT floor." The USEPA has collected data from emission tests on 80 coal-fired boilers. If the boilers are ranked according to the percent reduction achieved, the average of the top 12 percent is a 91 percent reduction from the mercury in the combusted coal.

At this point in time, in-use reductions from power plants accrue primarily as "co-benefits" associated with technologies designed to control pollutants other than mercury such as oxides of nitrogen (NO_X), sulfur dioxide (SO_2) and particulate matter

[1] NESCAUM, Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action, October 2003. See www.nescaum.org.

(PM). All coal-fired power plants have at least some air pollution control devices, such as electrostatic precipitators or baghouses (also known as fabric filters) for particulate control; wet or dry scrubbers for SO_2 control; and low-NO_X burners, selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) for NO_X control. Most of these controls can have impacts on mercury emissions and speciation. Electrostatic precipitators, fabric filters and wet and dry scrubbers all have demonstrated particular promise in this regard.

A number of power plants already achieve impressive mercury reductions with technologies that are designed to control other pollutants. For example, four bituminous coal-fired plants with dry scrubbers and fabric filters each captured more than 95 percent of the mercury contained in the combusted coal during emission tests. Some plants burning subbituminous coal that are equipped with fabric filters and other stack controls achieved capture of 74 to 86 percent of the mercury in the combusted coal during emission tests. For example: an 86 percent mercury reduction was measured at a boiler equipped with a fabric filter and low NO_X burner; a 74 percent mercury reduction was measured at a boiler using limestone injection and a fabric filter; and an 84 percent mercury reduction was measured at Intermountain at a plant which burns subbituminous and bituminous coal in a boiler equipped with a low NO_X burner, a wet scrubber, and a fabric filter.

As these examples illustrate, mercury co-benefits from existing air pollution control technologies have already proven to be quite substantial. Moreover, at the time of these emissions tests, there was no attempt to *optimize* controls for mercury removal. Thus, the potential exists to increase mercury removal significantly using various optimization strategies on existing controls.

Emerging Mercury-Specific Control Technologies

Mercury-specific control technologies are well on their way to commercial availability. For example, activated carbon injection technology is being successfully demonstrated in both pilot and full-scale applications. The results indicate that mercury control efficiency of over 90 percent is feasible for power plants, with costs that are comparable to the costs of NO_X removal required under the federal program to achieve national ambient air quality standards for ozone (i.e., in the range of two mills per kilowatt hour). According to an article in a recent American Coal Council publication, activated carbon injection "requires minimal new capital equipment, can be retrofit without long outages, and is effective on both bituminous and subbituminous coals," and "it appears unlikely that compliance with pending mercury reduction regulations will result in significant fuel switching."[2] Recognizing this opportunity, a permit issued in June 2003 for a new power plant in Iowa burning western subbituminous coal requires mercury reductions of over 80 percent using activated carbon injection.

Other promising technologies include enhanced wet scrubbing, K–Fuel®, and Powerspan-ECO™. Enhanced wet scrubbing technology promotes the oxidation of elemental mercury in the flue gas prior to entering the scrubber, such that as high a fraction as possible of the total mercury is in the oxidized state and hence more easily removed in the scrubber vessel. Many approaches are under development to accomplish this goal, including those using chemical reagents, fixed catalysts, and high-energy oxidation.

KFX's K–Fuel® is a processed coal derived from western subbituminous coals. It is lower in ash, higher in BTU value, and produces lower pollutant emissions than the parent coals. K–Fuel® is processed in two-steps—physical separation and thermal processing—to produce a fuel that is higher value and "cleaner" than the original coal. The process involves elevated temperature and pressure, greatly reducing the moisture content of the coal. The mercury is volatilized and subsequently captured in a carbon-bed reactor.

Powerspan-ECO™ is a post-combustion multi-pollutant control technology. It consists of a high-energy oxidation reactor followed by an ammonia-based scrubber and a wet electrostatic precipitator, which captures the products of oxidation. Fertilizer byproducts are generated (ammonia nitrate and sulfate), which should contribute to the overall economics of the technology.

While NESCAUM's new report focused on the above four mercury-specific control technologies as those closest to commercialization, the Subcommittee should be aware that several *additional* mercury control technologies have also emerged from the laboratory and are now being tested, including EPRI's "Toxecon" process, the use of flyash as a sorbent at GE Power Systems and CONSOL Energy, promising chemical (vs. physical) sorbents at Amended Silicates/ADA Technologies, and var-

[2] Durham, Michael, *Tools for Planning and Implementing Mercury Control Technology,* American Coal Council, 2003.

ious metal amalgamation approaches. The fact that several of the above approaches were not even *in existence* 2–3 years ago illustrates the rapid pace of research in the area of mercury controls.

Barriers to the Development of Mercury Controls for Power Plants

Due to the pace of technology development, the only real remaining barrier to controlling mercury emissions from power plants is not a question of technology; it is a question of will: it is the current absence of the regulatory driver needed to create the opportunity—the demand—for mercury control technologies to come to market. At this point, coal-fired power plants are not installing aggressive mercury control technologies because they cannot do so; they aren't simply because there is no *requirement* for them to do so.

In September 2000, NESCAUM issued a report summarizing an in-depth study of the technology-forcing effects of environmental regulatory requirements.[3] This study looked at the regulation of nitrogen oxide (NO_X) emissions from coal-fired boilers, sulfur dioxide from coal-fired boilers, and automobile emissions. It concluded that regulations with well-defined targets and compliance deadlines drive innovation in control technology, resulting in dramatically lower implementation costs than initially projected. Similar analyses of approximately a dozen major regulatory initiatives ranging from CFCs to landfill leachate show that initial cost estimates were at least double the actual costs and often far higher.[4]

Simply put, the principal barrier to the development of cost-effective controls for mercury emissions from power plants has been EPA's failure to date to establish an appropriate MACT standard for this sector, and we have no doubt that the documented history of regulatory-driven technology innovation and cost reduction will repeat itself if and when EPA does establish an appropriately stringent mercury MACT standard.

Coal-fired boiler operators suggest that EPA proceed only gingerly—if at all—with mercury reduction requirements because, they claim, there are no "commercially available" mercury control technologies. This suggestion dovetails closely with the above discussion of barriers. When does an "available" technology become "commercially available"? When it provides competitive advantage to the buyer, or when the buyer is required to modify its practices to meet a larger societal need, e.g., through regulation. "Commercial availability," then, resembles a "chicken or egg" scenario. Which comes first, "commercial availability" or regulatory obligation? Per the above discussion concerning barriers, history shows that well-designed regulatory requirements with appropriate lead times result in the commercialization of technological innovation, not vice versa.

Let's also consider precisely what industry opponents mean by "commercial availability." Southern Company recently indicated that "There are *currently* no commercial technologies that are available for controlling mercury from coal-fired power plants. There are no vendors that are offering process systems that are supported by *guarantees* from the vendor for mercury control performance under *all* the conditions that an ordinary power plant is expected to encounter over the course of normal operating conditions and timelines" [emphasis added].[5] These caveats suggest that industry seeks zero risk regarding mercury control performance, which leads me to wonder if it would accept a corresponding zero percent *return* on any mercury control investments made under such caveats.

In sum, we need to expose the "commercial availability" argument for the red herring that it is. Other red herrings lie in the wings, including (a) the technologies don't deliver good results all the time, (b) the cost is too high, and (c) the technologies can't be installed in time. History shows that market forces will capably address each of these concerns. Technology rapidly gets the kinks out and becomes reliable, costs drop dramatically, and the market gets the job done on time. But that won't happen until there is a market, and there won't be a market until there is a driver—a stringent mercury MACT.

In conclusion, I am reminded of an aphorism that arose during earlier NO_X negotiations with the power sector, but seems no less applicable to mercury emissions: "Ask an engineer to do something, and you get nothing but problems. Tell an engineer to do something, and you get nothing but solutions." Today, we are getting significant mercury reductions as co-benefits from non-optimized controls for other pollutants. We have full scale tests on new, cost-effective control technologies that re-

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[3] NESCAUM, *Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers,* September 2000. See www.nescaum.org.

[4] Worldwatch Institute, *Working for the Environment,* Paper #152. See www.worldwatch.org.

[5] Monroe, L., Southern Company, from *Mercury Rising,* UtiliPoint IssueAlert, July 15, 2003. See www.utilipoint.com/issuealert/print.asp?id=1749.

duce mercury substantially from a variety of coals. And we have new, even more promising mercury control technologies coming out of the labs. Let's tell our power sector engineers that it's time to reduce mercury emissions by 90 percent and begin to reap the public health and environmental technology benefits that the resulting market will bring forth.

DISCUSSION

Chairman EHLERS. Thank you all very much. In response to your last comment, I should defend engineers, but I won't. But I would mention the way to get a physicist to solve a problem is to tell them that there is no solution possible, and you will soon have ten different solutions.

LESSONS LEARNED FROM THE STATE OF FLORIDA RESEARCH

Very good testimony. And a number of questions that I have, I think we are going to need a second round just to accommodate my questions. But I am trying to—well, Dr. Krabbenhoft, first, were you involved in the work in the Everglades, and can you tell us what we learned from the experiment there following the regulation of the incinerators in Florida? And I should mention, even though most of the discussion has been about power plants burning coal, the first regulations were on medical incinerators, which tend to have a lot of mercury in them because of the medical products. So that has been regulated for some time. Can you enlighten us on what has been learned so far with that?

Dr. KRABBENHOFT. Yes, Mr. Chairman. I have been working on the mercury issue in south Florida since 1995. Over that period of time, we have learned a lot about what controls mercury cycling in the environment.

In short, over the past five or six years, there has been a notable decline in fish mercury concentrations observed in sport fish particulate gas and it is to the level of about a 60 or 70 percent reduction in fish tissue concentrations. Over that same period of time, the State of Florida has concluded that this reduction in fish tissue concentration is related to the rules that were implemented around 1990 that had an effect on municipal and medical waste incineration in south Florida to reduce mercury emissions in the southern peninsula of Florida. This corresponding reduction in fish mercury concentrations has been linked to that. They have done modeling exercises to see if that level of reduction in air emission sources could result in those fish mercury concentration declines, and the answer was, in short, yes.

That is one of the rare examples, here in the U.S., where you can look at an air emission reduction and infer what happened ecologically.

THE DIFFERENCE BETWEEN METHYLMERCURY AND ELEMENTAL MERCURY

Chairman EHLERS. Let me just ask a few questions to improve my understanding. My understanding is that the only real risk is from methylmercury, that the elemental mercury that is out there, the mercury oxides, chlorides, and so forth don't really seem to pose a health risk, but just the methylmercury. Is that correct?

And that is because it is absorbed by living organisms and then concentrated on the food chain. Is that a correct statement?

Dr. KRABBENHOFT. Yes, the fraction of mercury in the environment that is methylated typically, say, in sedimented water, is less than one percent to a few percent, a very small fraction of the total pool. But it is that small fraction that by the time you get into the part of the food web where you would consume, say, a top predator fish, it essentially comprises all of the mercury in those fish tissues. So that inorganic fraction, the oxides of the elemental mercury, does not bioaccumulate to the top levels of the food web. So it is that fraction of the mercury that humans and other top carnivores or predators are exposed to.

HUMAN RESPONSE TO METHYLMERCURY EXPOSURE

There are also biochemical reasons in our bodies as well as other vertebrate organisms that allow methylated mercury to get into parts of our bodies that the inorganic fraction does not. So that is in addition to not only bioaccumulation aspects, but also biochemically. It behaves differently once in our bodies.

Chairman EHLERS. The Mad Hatters became ill simply because they had such a huge concentration of elemental mercury they were working on.

Dr. KRABBENHOFT. That was a case of just gross exposure to the inorganic mercury, correct.

Chairman EHLERS. Yeah. All right.

FRESH WATER VS. MARINE WATER

You made the comment about marine—you know a lot more about fresh fish consumption and pollution than marine. What is the likely difference? Is it the minerals in the water in the ocean that make the difference or you don't know whether the mercury is distributed worldwide. What is the difference?

Dr. KRABBENHOFT. The key difference is that in most freshwater systems, because they are much shallower than the ocean, scientists call upon mercury methylation to occur at the sediment water interface. Therefore, the likelihood of that methylmercury production zone being linked to the food web is not hard to imagine at all. However, in the ocean where you have thousands and tens of thousands of feet of separation from where the harvestable fish are swimming. From the bottom of the ocean where it may be methylated, it is very difficult to come up with a reasonable or plausible link between a sedimentary-based methylation site and fish swimming near the surface of the ocean. That is the problem that we just can't come up with a conceptual model that is reasonable based on our freshwater experience. Therefore, several of us are proposing links to coastal margins, actually, food web links of those marine fisheries to coastal margins.

Chairman EHLERS. To what extent are the ocean fish contaminated with mercury compared to the freshwater fish?

Dr. KRABBENHOFT. Some of the highest levels of mercury in fish, on average, in fact, are from the marine fish.

Chairman EHLERS. Really?

Dr. KRABBENHOFT. Yes.

Chairman EHLERS. And what is the concentration of methylmercury in the ocean water compared to freshwater?

Dr. KRABBENHOFT. We can use the example that if we use our standard procedure, which is the best going right now, we would take a freshwater sample and analyze methylmercury from it and we apply that procedure to ocean water, we can not detect methylmercury. If we use adapted procedures with much higher volumes and stripping methylmercury out of a larger volume, we can measure it. But the methylmercury in any case in ocean water is extraordinarily low. And that is part of the conundrum. How can we get such high levels in these marine fish when the levels are so extraordinarily low?

Chairman EHLERS. Unless they eat an extremely greater amount of fish, of smaller fish.

All right. My time has expired. I will recognize the Ranking Member, Mr. Udall.

DEVELOPMENT OF SPECIFIC TECHNOLOGIES FOR MERCURY ABATEMENT

Mr. UDALL. Thank you, Mr. Chairman. I, too, want to thank the panel. And your testimony has been very educational.

If I could, I would start with Mr. Colburn. In your written testimony, you state that current technologies can achieve an impressive, I think, 95 percent reduction of mercury in power plants. I think what is remarkable about it is in part because this is shown even in the absence of specific controls for mercury. Since 95 percent of mercury can be removed as a co-benefit, is there a need for the development of specific mercury control technologies?

Mr. COLBURN. I think, Congressman, that that is really a function of letting the market pick the best solution.

Mr. UDALL. Uh-huh.

Mr. COLBURN. We should require a mercury reduction result, and then if individual plants in their market conditions can achieve that through co-benefits, more power to them. If they need mercury-specific control technologies to achieve that, then market options should be there for them to do so. The principle reason, as I see it, that most of those plants performed as well as they did is because they have a fine particulate matter control technology called a baghouse or a fabric filter. There is carbon in the gas. That allows absorption with mercury. The baghouse provides greater coverage, greater residence time, a greater exposure to the carbon by the mercury, and thus, more is removed. Baghouses aren't rocket science, and they could be installed on other plants, if the plants chose that as their route. But that is being done today.

The oxidation opportunities that Dr. Offen mentioned are also significant and I suspect that several of those plants also had SCR before the baghouse, but those technologies exist. The reason other plants have done less well is many of those plants don't have baghouses. Does that answer your question?

Mr. UDALL. That is helpful. Yes.

Dr. Offen, would you like to comment on that particular question or add your comments?

Dr. OFFEN. Yes. There were a number of comments that were made. What Mr. Colburn said was correct about the plants that

have very high removals. They do have, typically, spray dryers and baghouse combinations, the particular set of controls that work very well on low-sulfur coals. They have to be eastern low-sulfur coal so they have enough chlorine in there to make all three work together.

What Mr. Colburn said about unburned carbon is also correct. For those plants that aren't able to burn the coal out totally and have some residue carbon left in there, that will help as long as the temperature where the particulate collection device is low enough. All of these are site-specific factors, so depending upon the plant situation, you would have to add other controls to get to any increased levels, especially those plants that are in the 10, 20, 30, and 50 percent range.

FEDERAL REGULATION'S EFFECT ON MERCURY REDUCTION

Mr. UDALL. Back to you, Mr. Colburn, again. You had some remarkable results, as we were mentioning, in the Northeastern States. And from what I understand, you did this in part because these municipal waste combustors had higher standards, three times as high as the federal standard. How important is it that federal mercury regulations allow States to institute more stringent controls than federal law prescribes? If the Northeastern States had not been able to increase control standards, in other words, preempt federal laws, could the Northeast have been successful in achieving this 55 percent in regional reduction?

Mr. COLBURN. We certainly would not have been able to achieve it, Congressman. If we had been limited, if the States did not have the opportunity to provide further protection to their citizens, it couldn't have been done. I should add, Congressman, that the sources have actually controlled about three times better than even the States required. We have been here and have done that as far as mercury controls on municipal waste combustors go. No, we just need to give the power plant sector the same motives to move forward with both the information needs that Dr. Offen mentioned and the control technology installations.

Mr. UDALL. So you are saying the combustors went three times beyond what the States were requiring which was three times beyond from the federal standards?

Mr. COLBURN. Yes. The federal standard is typically 80 micrograms per cubic meter. The States typically did a standard of 28. And the municipal waste combustors are operating in the 5 to 10 area.

RELATIONSHIP BETWEEN GOVERNMENT REGULATION AND TECHNOLOGY DEVELOPMENT

Mr. UDALL. Dr. Offen and Mr. Colburn, one of my worries is that we lag behind if we don't put these new standards in place, lag behind other countries in the development of their technologies. Do you foresee a point in which if we don't make it clear what our standards are that, when we do, because I think this is a matter of not whether but when and how, that we will actually be buying that equipment and generating that technology from other coun-

tries as opposed to within our own environmental technology sector?

Mr. COLBURN. Congressman, I think that is not only a perceptive point, I think that is an accurate one. I had one technology vendor recently say to me that the showstopper for their technology creation and development would be if there is not a good mercury MACT rule. And I think that is representative of the other technology developers out there.

An interesting calculation, I certainly don't have it at the tip of my tongue, would be how many jobs are there in the control development manufacture and installation side of the coin versus the power plant operation and extraction industries? I wouldn't be surprised if the delta between those two is smaller than any expect.

Mr. UDALL. I see my time has expired, but I did want to mention and show the Chairman as well, that on the coal consumption, a million ton basis, China and the U.S. add up to about 50 percent. And I am curious if the Chinese are developing any of this kind of technology. And if they are not, then, of course, we are in a race with the EU countries, I would imagine, and perhaps Japan in fighting this technology with the Chinese, which would be an enormous market for us. Would that be correct from what you understand?

Mr. COLBURN. I don't have direct knowledge of that, but I have no reason to dispute the conclusion that they must be looking at that.

Mr. UDALL. Thank you, Mr. Chairman.

Chairman EHLERS. The gentleman's time has expired.

Next, we recognize the gentleman from Minnesota, Mr. Gutknecht.

HOW FEDERAL AGENCIES ARE RESPONDING

Mr. GUTKNECHT. Thank you, Mr. Chairman. And I was deadly serious, I have become incredibly interested in this subject. And the more I learn about it, sometimes, it is more disturbing what I learn is out there.

First of all, I guess I would ask all four of you maybe to just respond as briefly as you can. Do you think that the EPA, the CDC, the FDA, and the other agencies that are involved in this are taking this issue as seriously as they should? Dr. Burke.

Dr. BURKE. Great question. I think they are taking it very seriously. They interacted very actively with the National Academy. They have active research at CDC, surveillance of the population at EPA, the development of regulatory approaches as well as research, and the FDA has been doing a lot of fact-finding. Unfortunately, they take three different directions sometimes, and we have not had a unified approach to really look from source to exposure to health endpoint, but I think that is beginning to take shape. Yes, they are taking it seriously.

Dr. KRABBENHOFT. I interact with agency members from most of the agencies that you listed there, and my conclusion is they take it very seriously. They don't necessarily agree, but my conclusion is they take it very seriously.

Dr. OFFEN. Of course, I will switch to the control technology portion of what they are doing. And as I mentioned in my discussion,

we work very closely with the Department of Energy but also with the EPA. We co-fund projects, and they were participants in all of the field tests that led to the graph that is at the end of your package, for example. So the answer is definitely yes.

Mr. COLBURN. Congressman, I would basically agree with the other three witnesses. I would also include the private sector, because they are taking it very seriously in terms of technology development. I guess the only equivocation I would have is that one does have to recall that EPA needed to be compelled through Court Order to issue the MACT rule at the end of this year and then to finalize it at the end of next year.

Mr. GUTKNECHT. That is part of the reason I raised the question. And I think you all eluded to it that, even in the consumption of fish, we have different agencies essentially saying different things. Now I am not sure that that is necessarily a bad thing, but I am also concerned, and this is a parochial interest, and part of the reason that has gotten me interested in this and I can't remember which one of you mentioned this, about the lack of setting clear standards. For example—I would assume some of you are familiar with the process of retorting and that actually, at one time, there were ten firms involved in that and now we have two, in part because the EPA has not promulgated the rules, which I think everyone assumed that they would.

Dr. Krabbenhoft, I see you were shaking your head. Is that okay?

Dr. BURKE. Let me try and sort out the question there. There has been a lot of uncertainty about the science, but clearly there are different missions for the agencies involved, which has led to different approaches to how they have gone about their efforts to limit mercury exposure and the health effects. I think EPA has been a leader in the research and pushing forward with the evaluation of the epidemiology. But clearly, there have been different points of view from CDC and FDA. I think this has led to some confusion and ultimately to the National Academy study, which we feel has unified the database, has looked across the endpoints of animal and human data and really tried to put an end to the different interpretations and come up with some definitive recommendations about the effects seen in the human epidemiology, provides a strong basis for EPA to move forward with the RFD, and that the scientific basis of the actions, although they might have different responsibilities, should be uniform across the agencies.

THIMEROSAL

Mr. GUTKNECHT. Let me just ask one last question, and I see the yellow light has already come on.

One of the other things, Dr. Burke, you mentioned unborn children. And what about small children and the use of—I believe it is called thimerosal. And I understand have been studies and some back stepping and so forth on that whole issue. What is your view?

Dr. BURKE. Well, I understand today there was a—the American Academy of Pediatrics came out with some new evidence that thimerosal in vaccines was not related to adverse effects. I have only heard that through the press. I think there is a lot of uncertainty, particularly at the very low doses that we are talking about. And there are questions about when is the most vulnerable period of de-

velopment? Is it in utero? Is it small children? We know the brain is very busy developing in small children. We also know that mercury is a strong neurotoxic agent, but we don't have all of the answers. I think that is why we depend upon the epidemiology from the most sensitive, the children exposed in utero. But frankly, there are effects throughout the life span, including cardiovascular effects on middle-aged men that we are just beginning to understand and sort out.

Mr. GUTKNECHT. I see my time has expired, and I might come back to that, because when you have small, underweight children and you give them three booster shots all in the same day, they are getting upwards of 75, is it microliters, or whatever the term is. I mean, it seems to me that is a pretty good jolt to anybody's system.

Dr. BURKE. There was concern, particularly about the premature infants and the regime of vaccination and a movement toward phasing out thimerosal as a preservative. It has important benefits. Vaccinations have been a tremendous public health breakthrough, but we have to balance those. And right now, the news appears to be good.

Mr. GUTKNECHT. All right. Thank you.

Chairman EHLERS. The gentleman's time has expired.

Next we call on the gentleman from Maryland, Mr. Gilchrest.

WHAT HAPPENS TO MERCURY WHEN IT ENTERS THE NATURAL ENVIRONMENT

Mr. GILCHREST. Thank you, Chairman.

Just to, maybe, Mr. Burke and Dr. Krabbenhoft. I was looking at it to make sure I pronounced your name right.

Three forms of mercury, or the three that were mentioned here, at least, oxidized, elemental, and methylmercury, are they all persistent in the environment, or do any of them biodegrade in the natural environment?

Dr. KRABBENHOFT. Those forms of mercury all interconvert, some on a very rapid basis. So if we go out and take a sample and have a certain percentage, say and a sample has methylmercury, we can come back a few months later and see a very different signal, because there are——

Mr. GILCHREST. So it might go from methyl to elemental to oxidized?

Dr. KRABBENHOFT. Yes. There is a constant interconversion. Now is there any——

Mr. GILCHREST. Is there a difference in freshwater in estuary or the marine environment? Would that change?

Dr. KRABBENHOFT. I have—certainly for the marine system there is not enough information to give you an answer.

Mr. GILCHREST. Could it change inside the fatty tissue of a fish from methyl to elemental to oxidized?

Dr. KRABBENHOFT. Certainly methylmercury could be demethylated to the oxidized inorganic mercury in our bodies, and that is one of the things that does happen, yes. But it is very slow——

Mr. GILCHREST. So it is not likely to change while it is in the fatty tissue of a fish?

Dr. KRABBENHOFT. It actually doesn't go to the fatty tissue. It goes to the muscle.

Mr. GILCHREST. Oh.

Dr. KRABBENHOFT. That is the difference between mercury and most other contaminants of concern. And that is why you can't filet it out or cook it out.

Mr. GILCHREST. But methylmercury is the dangerous form of mercury that could cause health effects as opposed to elemental and oxidized mercury?

Dr. KRABBENHOFT. None of them are good for us——

Mr. GILCHREST. Okay.

Dr. KRABBENHOFT [continuing]. That is for sure. Methylmercury is more toxic gram per gram than the others for a variety of reasons that probably Dr. Burke is more qualified to answer.

SCIENTIFIC BASIS FOR EPA STANDARD

Mr. GILCHREST. Is it—Dr. Burke, you mentioned that the National Academy of Science has tried to find some uniform, I guess, system to determine is it safe levels of mercury in humans and have they come up with a unified statement or policy on that?

Dr. BURKE. The National Academy report reviewed the body of evidence and make recommendations to EPA. It reviewed the basis for the EPA standard, which at that time, was based upon a poisoning episode in Iraq. And we are most concerned about dietary, consumption of fish that have mercury. So we recommended they change the basis for their standard and use the human epidemiology and provided a presentation of that information, yes.

Mr. GILCHREST. So NAS made a recommendation to EPA for EPA to change the standard they had been using?

Dr. KRABBENHOFT. Change the scientific basis for it.

Mr. GILCHREST. Oh, I see.

Dr. KRABBENHOFT. In fact, what we did was reaffirm the standard that they were using, because within that range, that appears to be a range with levels of uncertainty that would be protective——

Mr. GILCHREST. So you are saying EPA pretty much had it right already?

Dr. KRABBENHOFT. EPA had it right, but we refined the basis for that being maternal exposure, through diet, through fish.

MERCURY IN THE CHESAPEAKE BAY

Mr. GILCHREST. So in an estuary like the Chesapeake Bay, what would be the prime source of mercury, methylmercury in particular? Would it be coal-fired power plants?

Dr. KRABBENHOFT. The knowledge I have of the Chesapeake, and there are research projects that are going on right now, and I believe I have them accurately that the majority of the methylmercury is made in the sediments of the Chesapeake itself, but it is——

Mr. GILCHREST. When you say it is made in the sediments of the Chesapeake itself, what do you mean?

Dr. KRABBENHOFT. The mercury that comes into the Chesapeake is overwhelmingly the inorganic, oxidized form both from air depo-

sition and from runoff. And the runoff gets contributions from a wide variety of sources.

Mr. GILCHREST. From as far away as Ohio?

Dr. KRABBENHOFT. Those would have to be air deposition, but certainly that is not implausible at all. But once in the ecosystem, that mercury that deposits either on streams that drain into the Chesapeake or directly on the Chesapeake itself quickly descend to the sediments. And there, a fraction of that mercury gets methylated. So it is converted in the environment to methylmercury. And so the majority of the methylmercury in the Chesapeake——

Mr. GILCHREST. How long does it take to go from the oxidized form to methylmercury while it is in the Bay?

[No response.]

Mr. GILCHREST. That will vary depending on the circumstances?

Dr. KRABBENHOFT. It varies depending upon the circumstances, but in short, what we have seen in our environment studies is this transformation is very fast.

Mr. GILCHREST. So the main source, whether it is the drainage from the land to the streams to the Bay or from air deposition, what would be the main source of that mercury, oxidized, elemental, or methyl? Is that—I mean, other than human activities, is it automobiles, incinerators for medical waste, coal-fired power plants?

Dr. KRABBENHOFT. I have not seen a mass balance, if you will, for Chesapeake Bay itself. Researchers who I know are doing that have done the calculations to suggest that most of the mercury, I believe, comes in through the sky——

Mr. GILCHREST. I see.

Dr. KRABBENHOFT [continuing]. And rains directly on the Chesapeake that way. And that is generally the calculation results that direct deposition is most important.

Mr. GILCHREST. Would you recommend that every fishing hole in the Chesapeake Bay and its tributaries have a sign talking about the contamination of methylmercury or is that not a problem to fish?

Dr. KRABBENHOFT. Go ahead.

Dr. BURKE. If I may help with this, the inland waterways, the rivers throughout Maryland actually have fishing advisories. The Bay itself——

Mr. GILCHREST. Well, I live there, and I don't see a lot of signs posted——

Dr. BURKE. No, the signs aren't there, but the advisories are there.

Mr. GILCHREST. Should the signs be there? The advisories are in the newspaper every once in a while.

Dr. BURKE. They should be there. They should be on the licenses, and we should have, as best we can, the best information we can have out there on the levels in inland waterways, not just in Maryland but throughout this country. In 44 of the States we have this problem. They are elevated. The levels from outside in the Bay appear to be lower, though.

THE BASIS FOR NATIONAL ACADEMY OF SCIENCE'S RECOMMENDATION

Chairman EHLERS. The gentleman's time has expired. We will start a second round of questioning.

And Dr. Burke, I would like to ask you a few questions about the studies on which your work was based. First of all, I am interested in the Seychelles study, which I understand, initially was just regarded as not having appropriate technique and so forth. So when the National Academy did their work, they basically disregarded that in setting their number. Now I gather from your testimony that with additional work down there, the Seychelles study has achieved some respectability. Now are they showing an effect at this point? Are they still showing very little epidemiological evidence of disease from——

Dr. BURKE. Right.

Chairman EHLERS [continuing]. Eating the fish?

Dr. BURKE. First of all, the National Academy did not disregard the Seychelles study. In fact, they very carefully evaluated that as well.

Chairman EHLERS. Well, I am sorry.

Dr. BURKE. Yeah.

Chairman EHLERS. That was a strong word to use.

Dr. BURKE. Okay.

Chairman EHLERS. You didn't incorporate that——

Dr. BURKE. But we didn't use it for the basis of our recommendation, you are correct.

Chairman EHLERS. Yeah.

Dr. BURKE. But we have always felt it is a well-conducted longitudinal study. And the update also sheds new light on the potential impacts. What we recommended, though, that for public health protection, when there are two positive studies, there really isn't a sound justification for using the negative study as the public health basis for moving forward. This update, I might add, did address one of the questions that we had, and that was that perhaps the children were young when they were evaluated and it was hard to get reliable test data. And now that the kids are a little bit older, we feel that they really validate and continue to improve their observations and move forward.

But it is a well-conducted, sound study.

Chairman EHLERS. Is that—is it coming into agreement, then, with the other studies or is it too early?

Dr. BURKE. No, it is not showing positive effects. The other ones do show detrimental impacts on neurodevelopment. Seychelles does not.

Chairman EHLERS. How do you explain that, and why would you pick the ones that show positive effects and not the one that shows negative effects or null effects, I should say?

Dr. BURKE. That is an important question. Our fundamental goal is to protect public health. And with two well-conducted studies that do show an effect, a public health based standard, the longstanding protocol to go about this is to select a critical study and a critical effect and use that to go forward, informed by the other studies as well. So the uncertainties introduced by the Seychelles

were important, however, the data from the other two studies and the overall weight of the animal testing really provided, we think, a sound, scientific basis.

Chairman EHLERS. So it was a combination of the animal studies plus——

Dr. BURKE. A wide variety of human observational studies throughout time, including poisoning episodes, as well as these three very important epidemiological studies.

Chairman EHLERS. Did you determine anything about the type of mercury that was involved in the study? Was it all methylmercury that basically did the damage?

Dr. BURKE. Yes, by measuring both maternal hair and cord blood, we feel that the primary source was fish consumption and therefore it would be the methylmercury form.

THE EFFECT OF REGULATION ON INNOVATION

Chairman EHLERS. Okay. I am becoming thankful that I don't particularly enjoy eating fish. But that is not true of most people in my State.

Dr. Offen, I want to ask you about the testimony of Mr. Colburn in which he indicated that if we have the requirement, then there will be more innovation. It is another way of saying, you know, necessity is the mother of invention, that once we set a standard, there will be a scramble to produce cost-effective methods of controlling mercury emissions. Is that something that you would agree with?

Dr. OFFEN. There is no doubt that if a standard—when the standard is set, the industry will meet it as they are going to abide by the law. I think the only question that I would raise is at what level and how fast. I would also like to point out that even in the absence of a standard, but yet in the expectation of standards, the industry has been spending quite a bit of money on mercury. Our program, as I made mention, has been going on for 15 years. And right now, at EPRI, within the programs that deal with power generation, EPRI also covers, you know, transmission distribution, nuclear, et cetera, but within fossil power generation, the mercury control research work is the largest effort that we have. So there is some substantial amount of work that is going on right now.

I would hark back to the experience we had with scrubbers in the early '70's as sort of a guiding principle, maybe an experience-based principle. Those were mandated and because of the building boom and the economic growth we had at that time, a lot of the power plants were built and therefore a lot of scrubbers were built in a very short period of time. About a year or two or three later, most of them—or many of them had quite a bit of serious trouble. And from a researcher's perspective, that was good, because that gave us a $10 million a year for 10- or 15-year program, but for the economy, it maybe wasn't so good. I think that is where the concern is with statements that if you just mandate it, the solution will be there no matter what the time schedule is and what the level is.

Chairman EHLERS. So you are saying mandate it and then give some time for the research and development to take place?

Dr. OFFEN. For the research to be completed that is already well underway.

DEPARTMENT OF ENERGY EFFORT TO CREATE NEW TECHNOLOGIES

Chairman EHLERS. Yeah. All right. You have mentioned the DOE program that they were doing. Is this to develop new control technology, or is there——

Dr. OFFEN. I am obviously speaking secondhand here, since I am not from DOE, sir.

Chairman EHLERS. Yes.

Dr. OFFEN. But in the work that we are doing with them and that we are familiar with, they are doing both development and evaluation. And the field tests program that I mentioned where we will be testing for one to two months at 16 different sites I would categorize as evaluation. But they have quite a few programs where they are also developing work. They have two processes they have developed themselves that they have also promoted, for example. These go along in parallel, because you just never know which process is going to be successful. And secondly, you don't know which is going to be the most cost-effective. And the paradigm, if I could say so, in the power industry, has been that the power industry needs options, because every plant is so different from every other plant. That is why we see 10 to 90 percent reductions right now.

Chairman EHLERS. Yeah. And every lump of coal is different from every other lump of coal.

When do you expect the DOE work and your work to be able to give some definitive answers as to what is the best and what are the most cost-effective control technologies?

Dr. OFFEN. That is a difficult question to answer, because it depends on the success we have. If the current programs are successful and we get good results, we will know a lot more in 2006 than we do now when the programs are over. If we continue to have a different line for every power plant and can't understand why, it will be longer.

Chairman EHLERS. I see.

Dr. OFFEN. As my written testimony said, what we see as the biggest uncertainty is our understanding of mercury chemistry.

Chairman EHLERS. Well, I have kept going on because we didn't have any more Members. But my time is expired. Mr. Gilchrest, do you have additional questions?

Mr. GILCHREST. Just a couple.

Chairman EHLERS. Go ahead.

Mr. GILCHREST. I was interested in your line of questioning, though.

THE CAUSE OF THE DECLINE OF MERCURY IN THE FLORIDA STUDY

I understand that mercury is not biodegradable. Just stop me if I am wrong with any of this. But it accumulates in the environment. It never goes away. It might change from one form or an-

other, depending on the conditions, but it basically, for all intents and purposes, is persistent.

Dr. Krabbenhoft, when you made a comment about reducing the source of mercury in Florida, you saw a corresponding decline of mercury in the environment. Does that mean that the mercury in the environment was decreasing or just not increasing?

Dr. KRABBENHOFT. First of all, your question about the biodegradability of mercury, that is absolutely right. Mercury is one of the elements, and as such, it can neither be created or destroyed. It is there. That separates it from many of the contaminants of concern.

Mr. GILCHREST. And can a physicist, maybe believing in the string theory, corroborate that comment or——

Chairman EHLERS. Well, I would have to disagree with the statement, of course, because physicists can't create or destroy mercury. But that is beside the point for this when you are talking about it as part of the biological system. He is absolutely correct.

Dr. KRABBENHOFT. With regard to the specific question about Florida, the waste streams in south Florida and the combustion systems in south Florida were heavily dominated, unlike many of the other areas of the country, by medical and municipal waste incineration. They do not burn, essentially, any coal for power production in south Florida. It is different than many other places. But because they burn a disproportionately high amount of medical and municipal waste in south Florida, the rules that were in place around 1990 to eliminate or reduce mercury into those waste streams had a, probably, larger effect in south Florida than other parts of the country. And so the State of Florida has estimated reductions in mercury emissions from their local emitters on the order of 70 or 80 percent.

Mr. GILCHREST. But the mercury that was there prior to 1990, is it still there?

Dr. KRABBENHOFT. Is the mercury there by and large, yes. Now mercury does re-emit as well, so if mercury rains down from the atmosphere onto water or land, it is fully capable of being reduced largely from photochemical reactions from the sunlight, UV reactions, back to gaseous mercury, and then it goes back to the sky.

Mr. GILCHREST. What percentage of mercury does that, then, would you say?

Dr. KRABBENHOFT. It is generally not big, on the order annually of, say—our dosing experiments in the field suggested somewhere around the order of, say, five or 10 percent or so.

ELIMINATING MERCURY EMISSIONS

Mr. GILCHREST. Mr. Colburn spoke about his success in scrubbing out mercury in maybe somewhere around 2015 actually eliminating all of the mercury that is being emitted by fossil fuel power plants. Is that a fairly accurate statement?

Mr. COLBURN. The entire elimination, Representative, the Governors didn't put a date on that. They wanted 70 percent—75 percent by 2010 and then just to keep working beyond that.

Mr. GILCHREST. I see.

Mr. Offen, is that an achievable goal for the rest of the country what New England seems to be doing?

Dr. OFFEN. We have not seen 100 percent elimination of a pollutant any place.

Mr. GILCHREST. Well, I am not talking about 100 percent, but do you think that what New England has done for a projection of 75 percent elimination of mercury from these power plants by 2010, is that a goal in any other area of the country, that you are aware of?

Dr. OFFEN. Again, I will return to my answer to Chairman Ehlers. I can't predict how successful we will be in the next set of tests. We continue to see quite big differences depending upon fuel and the power plant. We see some successes, and we see some failures. And it continues that way.

Mr. GILCHREST. Sure.

Dr. OFFEN. Then the other question always is cost. You could create a scenario where every plant burned low sulfur eastern bituminous coal and had added to their current pollution controls a spray dryer and a baghouse and you would get down there. I don't know that that is the policy that you want to make.

Mr. GILCHREST. Mr. Colburn, have you benefited from the kind of coal that emits less sulfur and less mercury and you had other conditions that are different from, let us say, Maryland or Texas or California?

Mr. COLBURN. Okay. I think that most of our coal is bituminous, and so we, no doubt, have benefited from that as opposed to other coals. But today, Representative, most of our reductions have been through hazardous waste and municipal waste combustors as well. The reductions that we have had from coal plants, because that commitment, that 50 percent by 2003 and 75 percent by 2010, is economy-wide. It is not a power plant control. It is an overall mercury emissions goal. And as I said, we have met the 2003 one. So while we may have some advantages when a mercury control regime is adopted for power plants, the only benefits we are getting at this point are purely the co-benefits that we all spoke of before.

Mr. GILCHREST. Thank you.

TRACKING MERCURY ONCE IT HAS BEEN EMITTED FROM A PLANT

Chairman EHLERS. The gentleman's time has expired.

Dr. Krabbenhoft, how well can we keep track of the mercury or how well do we keep track of the mercury once it goes up the stack? And I am really getting at the local, regional, global question. Are we in the process of cleaning up to protect the people downwind from the power plant or is this because it is a global matter and every nation should be doing it? What insight can you give me on that and how well can you measure the deposition in the local environment, you know, say 40, 50, or 60 miles from the plant?

Dr. KRABBENHOFT. The technologies to do that are relatively new. By that, I mean probably within the last five years, the instruments that can actually be deployed in the field and distinguish those forms of mercury. So that has been a hindrance that we have only had an instrument capable of doing that for a relatively short period of time. If you deploy those instruments in the field, you can do a pretty good job of, A, measuring what is coming

out and few, but some studies have actually gone and followed through to watch the interconversions that happen post-release. Those are all very recent studies. But yes, you can do it. Yes, you can keep track of it. Yes, you can then apply models to predict how far it is raining out.

Chairman EHLERS. And what sort of—how many parts per million or parts per billion are we talking about when you are detecting this?

Dr. KRABBENHOFT. That we are detecting?

Chairman EHLERS. Yeah.

Dr. KRABBENHOFT. The instruments that are used in the field presently can see picogram quality—picogram per meter cube quantities, so extraordinarily low.

Chairman EHLERS. Um-hum.

Dr. KRABBENHOFT. So sensitive that you can't apply it near the source, because it overwhelms the detectors.

Chairman EHLERS. Yeah. Just as a matter of curiosity, what methodology do you use?

Dr. KRABBENHOFT. Detection is always done by atomic fluorescence. It is a wonderfully sensitive, ancient measurement, but it is wonderfully sensitive for mercury. The real work is done on the front end for separating out the forms using a variety of deneuters and columns and traps, et cetera.

Chairman EHLERS. Okay. Okay. So you look at the green lines, the famous green lines of mercury?

Dr. KRABBENHOFT. Yes.

GLOBAL, LOCAL, AND REGIONAL SOURCES OF MERCURY

Chairman EHLERS. What do we know about the quantity of mercury emissions from utilities that deposit in the local environment? How does that compare to the global load that an area may already have?

Dr. KRABBENHOFT. That is an area that, quite frankly, is underexposed in terms of our understanding. A vast majority of the studies to date have been done in truly remote settings. And I really believe the reason for that is just curiosity. How could you possibly get this much mercury in the wildlife in a setting that is so remote? And because of that, our understanding of the near field—near source field is underappreciated or underevaluated at this point. But certainly where researchers have gone into near field source field environments, you see much higher concentrations. So to use the example, we have recently collected data in East St. Louis, Missouri where we see levels of reactive gaseous mercury and particulate mercury on the order of 20,000 to 25,000 picograms per cubic meter whereas if we go to a remote location, you will see a number of about three. So there is tremendous gradient.

Now how do those gradients transition? We don't know. We need—we definitely need to do more work in those near source field areas.

Chairman EHLERS. And just one other question on that. We have largely talked about power plants as being the source or incinerators. Are there other sources of this? You mentioned the high readings within the urban area. Are there other sources that we have around?

Dr. KRABBENHOFT. Other sources of mercury, other than the ones that we have discussed today, the power plants——

Chairman EHLERS. Right.

Dr. KRABBENHOFT. Yes. Certainly other facilities like chloralcolyte plants are still a source of mercury today to the environment. Another one is metals melting. In fact, the high concentrations that I was speaking of in St. Louis, we don't believe that is contributed to any substantial degree—by coal combustion at all. We believe, in fact, that it is coppers melting. So yes, there are other sources that, I guess, haven't seen their day yet.

Chairman EHLERS. Yes. Okay.

Oh, the staff just reminded me. I haven't gotten to the global part here yet of the local, regional, global. Are you able to track mercury coming in from other countries and some way differentiate it? And how much of the load, on average, across the United States is from our own sources and how much is from global sources, including our own?

Dr. KRABBENHOFT. Well, if you look at the amount of mercury being released to the global environment from the U.S. versus the world, it is not a big proportion, five or 10 percent. But the real question is how much mercury raining out——

Chairman EHLERS. Yeah.

Dr. KRABBENHOFT [continuing]. In the U.S. is coming from our sources versus global sources.

Chairman EHLERS. Yeah. And that is my question.

Dr. KRABBENHOFT. That, I personally do not believe we have an answer for. The way you have to go about looking at that is looking at our own stacks and studies on our stacks, the mass account. You do all of the Lagrangian following of that plume and watch it through time to see how much of that mass and that plume drops out over what distance and understand what the footprint of that particular source is. Those kinds of things, quite frankly, have not been done, or if they have been done, they haven't been done enough.

Can I or anybody else distinguish Asian mercury coming in from European or California mercury by the time you get to New England? No.

Chairman EHLERS. There are ways you could determine it, if you wanted to do the experiment. I mean, you could use radioactive mercury and track it and see how far it goes.

Dr. KRABBENHOFT. Or even better yet, stable isotopes of mercury. We use those all of the time. That is how we do our new mercury versus old mercury source, so we wouldn't have to release a radioactive form. But yes.

Chairman EHLERS. Yeah.

Dr. KRABBENHOFT. You can do that. We proposed that once to the DOE. It didn't get very far.

Chairman EHLERS. Well, that is interesting.

Okay. Yes, Dr. Offen.

Dr. OFFEN. Mr. Chairman, I know that some of my colleagues at EPRI have looked at that. I am not capable of discussing it at any great depth, but with your permission, I would like to submit a response to your question, for the record.

Chairman EHLERS. I would very much appreciate that and—I was just going to close, but we will see if Mr. Gilchrest has any other questions.

Mr. GILCHREST. Just a quick question, Mr. Chairman. Thank you very much.

FISH CONSUMPTION IN THE SEYCHELLE ISLAND STUDIES

Dr. Burke, in, I guess it is the Faroe Islands, New Zealand, the Seychelles Islands, you did studies on the vulnerable population of unborn children looking at the amount of mercury in their system based on fish consumption.

Dr. BURKE. We looked at mercury exposure to the mother——

Mr. GILCHREST. Okay. And was that——

Dr. BURKE [continuing]. And related that to developmental outcomes in the children.

Mr. GILCHREST. Was that based on fish consumption?

Dr. BURKE. Yes.

Mr. GILCHREST. On the level of mercury contamination in the fish in these areas, were they all fairly high, pretty similar in those three places——

Dr. BURKE. Well, actually——

Mr. GILCHREST [continuing]. Which is why you chose them?

Dr. BURKE. Well, actually, in the Seychelles, for instance, they consumed ocean fish, and they are similar to the levels we see in this country. But they consume a very high diet of fish with 12 meals a week, which would be very unusual——

Mr. GILCHREST. Right.

Dr. BURKE [continuing]. Here in the U.S. They were chosen, though, because of——

Mr. GILCHREST. They seem to have——

Dr. BURKE [continuing]. Their dietary patterns.

Mr. GILCHREST. Yes.

Dr. BURKE. Yes.

EFFECTS ON WILDLIFE

Mr. GILCHREST. So you could say—I mean, I don't want to put words in your mouth, but if you evaluated the amount of mercury in fish in the Chesapeake Bay, whether they were minnows or catfish or rockfish or whatever, would there be similar concentrations of mercury in the Chesapeake Bay fish as there were in Seychelles?

Dr. BURKE. Well, that is an important question. Actually, there is a wide range, like a 20-fold difference in the concentrations of mercury, depending upon the species.

Mr. GILCHREST. Oh, gee.

Dr. BURKE. And the fish we are most concerned about for the average consumer are the large——

Mr. GILCHREST. Right.

Dr. BURKE [continuing]. Predator fish.

Mr. GILCHREST. So striped bass would be a concern?

Dr. BURKE. Actually, striped bass is—does not have——

Mr. GILCHREST. Really?

Dr. BURKE. And I might add that crab cakes don't have mercury issues as well.

Mr. GILCHREST. How about oysters? We are pretty safe with oysters?

Dr. BURKE. I actually don't——

Mr. GILCHREST. So which fish in the Chesapeake Bay, then, would have high concentration——

Dr. BURKE. The Chesapeake Bay, in general, the—for the main body of the Bay, the levels are low.

Mr. GILCHREST. Fairly minuscule?

Dr. BURKE. It is—right. It is the inland rivers where, because of localized sources——

Mr. GILCHREST. Now when you say inland rivers, are you talking—is that——

Dr. BURKE. Like the Back River, where the advisories are. It is the inland waterways.

Mr. GILCHREST. Like the Sassafras River versus the Back River?

Dr. BURKE. Yes.

Mr. GILCHREST. The Back River would be worse than the Sassafras?

Dr. BURKE. I am not quite sure of that specific comparison.

Mr. GILCHREST. But it would be those tidal basins——

Dr. BURKE. Yes.

Mr. GILCHREST [continuing]. That would be of more concern than the main focus of the Bay?

Dr. BURKE. Yes, because of the biology of the Bay and the nature of the food chain of the fish.

Mr. GILCHREST. Since fish consumption is part of the, I would assume, main criteria for determining how dangerous this is, and since probably people in Kent County, Maryland or Anne Arundel County don't eat as much as they do in the Seychelles, would not be put at that same risk. Have there been studies done to evaluate the neurological development of things like eagles and osprey and blue heron, those kinds of things?

Dr. BURKE. I am not aware of ecological studies that way. That was a little bit beyond the scope of the National Academy work.

Mr. GILCHREST. Could you assume that there would be potential mercury poisoning in those animals that do eat fish everyday?

Dr. BURKE. Absolutely. I think that we would see the same kind of bioaccumulation and high level exposure to the nervous system.

Mr. GILCHREST. Are you aware of any type of study that would look at that?

Dr. BURKE. I can get back to you on that, but——

Mr. GILCHREST. Thank you. Thank you.

Yes, sir?

Dr. KRABBENHOFT. There are some studies in USGS of the Patuxent National Wildlife Testing Center where they are looking at methylmercury exposure and the toxicological effects to methylmercury exposure at the egg level of several of the species that you have just named. And the short answer to your question is yes, there are effects. It does have an appreciable affect on the successful hatching rate of those birds.

Mr. GILCHREST. Thank you.

Mr. Colburn.

Mr. COLBURN. I was just going to reinforce that, Representative. There has been some work done on loon, which of course, eat fish, along the lines mentioned by Dr. Krabbenhoft in the Northeast.

Mr. GILCHREST. Thank you very much. Thank you, Mr. Chairman.

CLOSING COMMENTS

Chairman EHLERS. Well, thank you very much for your questions. They have contributed to this hearing.

With no further questions, I would like to conclude the hearing with several comments. I think it is clear from today's hearing that there is compelling evidence that consumption of fish contaminated with mercury is a serious health threat. I also think we learned that there is a local effect from emissions from utility sources as well as a global effect and that reducing emissions from these sources will likely lead to reduced loading in the environment.

On the technology side, it also seems clear to me that while current technologies do achieve significant mercury reductions as a co-benefit, we have much to do to develop the technologies specific to mercury control. It appears that it may take regulation before we create a sufficient market that will drive innovation and commercialization of these technologies. Past experience, as Mr. Colburn has said, has certainly demonstrated that major advances in technology development follow regulation in many fields and often at much lower costs than initially projected. But we will see how this plays out. I assume that the EPA is likely to set a standard some time in the next month or two. And we will as Dr. Offen has pointed out, the time allotted to solve the problem could have a direct impact on the cost to the economy generally.

I certainly want to thank all of you for your participation at the hearing today. It has been a good cross-section of expertise. I, frankly, think we couldn't have had a better panel broadly representative of the issue from the Government, industry, and academia. And so I appreciate not only your testimony but your wisdom and your willingness to sit through all of these questions we have thrown at you.

If there is no objection, the record will remain open for additional statements from the Members. And also, Members may request answers from you, and we ask that you be kind enough to respond to any follow-up questions that the Subcommittee Members may send you. Without objection, so ordered.

Thank you, again, for your service, for your testimony, and keep up the good work. It is my pleasure to declare the hearing adjourned.

[Whereupon, at 3:44 p.m., the Subcommittee was adjourned.]

Appendix 1:

Biographies and Financial Disclosures

BIOGRAPHY FOR THOMAS A. BURKE

Thomas A. Burke is a Professor and Associate Chair at the Johns Hopkins Bloomberg School of Public Health, Department of Health Policy and Management, with joint appointments in the Department of Environmental Health Sciences and the School of Medicine, Department of Oncology. Currently he is Director of the School's newly formed task force, Scientist Working to Address Terrorism (SWAT). The goals of the task force are to provide: 1) scientific basis for rational action; 2) accurate advise for public agencies and profession and 3) develop short training for targeted groups via web, CD–Roms, etc. He is also Co-Director of the Johns Hopkins Risk Sciences and Public Policy Institute. His research interests include environmental epidemiology, the evaluation of community exposures to environmental pollutants, the assessment and communication of environmental risks, and the application of epidemiology and health risk assessment to public policy. He was Principal Investigator for the Pew Environmental Health Commission aimed at revitalizing the national infrastructure for environmental health. He is particularly interested in health and environment in the cities.

Prior to his appointment at Johns Hopkins, Dr. Burke was Deputy Commissioner of Health for the State of New Jersey. He has also served as Assistant Commissioner for Occupational and Environmental Health at the New Jersey Department of Health, and as Director of the Office of Science and Research in the New Jersey Department of Environmental Protection. During his tenure with the State of New Jersey, Dr. Burke established a number of exposure research efforts and environmental risk assessment programs at both the Departments of Environmental Protection and Health. He served as the scientific coordinator for many of the State's major investigations, including investigations of toxic contaminants in drinking water, the evaluation of dioxin contamination from industrial sources, and the investigation of chromium exposure in urban areas from industrial waste used as landfill.

Dr. Burke is the Chair of the Advisory Committee to the National Center for Environmental Health of the Centers for Disease Control. He also serves as a member of the Executive Committee of the EPA Board of Scientific Counselors. An editor of the book, *Regulating Risk: The Science and Politics of Risk,* he served on the National Academy of Sciences Committee on Risk Characterization. He has been a member of the Council of the Society for Risk Analysis and has served on the Office of Technology Assessment Advisory panels on Research on Risk Assessment of Chemical Carcinogens, and Managing Nuclear Materials from Warheads. He was also a member of National Academy of Sciences Committee an Risk Characterization, Panel on Separations Technology and Transmutation Systems, and Committee on Remediation of Buried and Tank Wastes, evaluating nuclear waste management options. He has served on EPA Science Advisory Board subcommittees, including reviews of the Clean Air Act Residual Risk Report to Congress and the Superfund Hazard Ranking System. He was also a member of the General Accounting Office expert panel to review the Superfund public health assessment process.

Dr. Burke received his Ph.D. in epidemiology from the University of Pennsylvania, his M.P.H. from the University of Texas, and his B.S. from Saint Peter's College.

JOHNS HOPKINS
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November 4, 2003

Vernon J. Ehlers
Chairman
Subcommittee on Environment, Technology and Standards
U.S. House of Representatives
Committee on Science
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

Dear Mr. Ehlers,

On November 5, 2003 I will be testifying at a hearing before the Subcommittee on Environment, Technology and Standards Committee entitled, "Mercury Emissions: State of the Science and Technology." Within the last three fiscal years, I have not received any federal funding that directly supports this subject matter.

If you have any other questions or concerns, please do not hesitate to contact me at (410) 614-4587.

Sincerely,

Thomas A. Burke PhD

Thomas A. Burke, PhD, MPH
Professor and Associate Chair

TAB/rld

BIOGRAPHY FOR DAVID P. KRABBENHOFT

Education:

Ph.D. Geochemistry/Hydrogeology–1988
University of Wisconsin-Madison

M.S. Geochemistry–1984
University of Wisconsin-Madison

B.S. Geology–1982
North Dakota St. University

David Krabbenhoft is a research scientist with the U.S. Geological Survey (USGS). He has general research interests in geochemistry and hydrogeology of aquatic ecosystems. Dave began working on environmental mercury cycling, transformations, and fluxes in aquatic ecosystems after completing his Ph.D. in 1988; and the topic has consumed him since. His work on mercury started with the Mercury in Temperate Lakes project in 1988, which served as the springboard for other environmental mercury research in the United States and around the world since. In 1994, Dave established the USGS's Mercury Research Laboratory, and since has assembled a team of multi-disciplinary mercury investigators in Wisconsin. The laboratory is a state-of-the-art, analytical facility strictly dedicated to the analysis of mercury, with low-level speciation. In 1995, he initiated the multi-agency Aquatic Cycling of mercury in the Everglades (ACME) project, and in 1998 organize and conducted a national synoptic sampling of mercury in sport fish, sediment and water from 122 sites across the United States for the USGS. More recently, Dave has been a Primary Investigator on the internationally conducted Mercury Experiment To Assess Atmospheric Loading in Canada and the United States (METAALICUS) project, which is a novel effort to examine the ecosystem-level response to loading an entire watershed with mercury. The Wisconsin Mercury Research Team is currently active on projects from Alaska to Florida, and from California to New England. Since 1990, he has authored or co-authored over 50 papers on mercury in the environment. In 2006, Dave will serve as the co-host for the 8th International Conference on Mercury as a Global Pollutant in Madison, Wisconsin.

BIOGRAPHY FOR GEORGE R. OFFEN

Manager, Air Emissions and Coal Combustion Product Management

Education: B.S., Mech. Engr., Stanford University; M.S., Mech. Engr., MIT; Ph.D., Mech. Engr., Stanford University

Experience

EPRI (1985–present). Dr. Offen manages EPRI's R&D program to cost-effectively reduce NO_X, SO_2, particulate, and air toxic emissions from utility boilers, as well as to increase the use of coal combustion products. He started EPRI's program on mercury control technology R&D in the late 1980's, and recently expanded it into the Integrated Environmental Control program. He has presented EPRI's air pollution control research results at numerous public meetings as well as to regulatory agencies, and coordinates EPRI's collaborations with DOE and EPA in air emission control technology. Currently, he is directing a study to obtain an understanding of mercury chemistry in the cooler temperature regions of a boiler and across catalysts used for NO_X reduction. Earlier projects included dry sorbent furnace injection for SO_2 control, fundamental research in combustion NO_X formation/destruction, and analyses of NO_X control combustion and post-combustion options in search of the least-cost combinations for any given site and NO_X limits.

Acurex Corporation, California (1974–1985). Manager, Energy Engineering. Responsible for projects in combustion testing and performance/environmental impact analysis of alternate fuels.

Earlier. Acting Assistant Professor and Teaching Assistant in Mechanical Engineering; Research Engineer in petroleum industry, and Test Engineer for conventional munitions in U.S. Air Force.

Associations. Air & Waste Management Association; American Society of Mechanical Engineers.

October 31, 2003

The Honorable Vernon J. Ehlers
Chairman
Subcommittee on Environment, Technology
and Standards
Committee on Science
U.S. House of Representatives
1714 Longworth House Office Building
Washington, D.C. 20585

Dear Chairman Ehlers:

Thank you for the opportunity to testify at your November 5 hearing on "Mercury Emissions: State of the Science and Technology." Per the Rules of the House of Representatives on "Financial Disclosure" of non-government witnesses before Congress, I submit the following:

> The Electric Power Research Institute has not received federal funding related to mercury emissions during the current year or the two preceding years.

Please feel free to contact me at (650) 855- 8942 if you have questions or require additional information.

Sincerely,

George Offen
Senior Technical Leader
Air Emission and Byproduct Management

BIOGRAPHY FOR KENNETH A. COLBURN

Kenneth A. (Ken) Colburn is Executive Director of the Northeast States for Coordinated Air Use Management (NESCAUM), a 36-year-old policy research and analysis organization representing state air quality agencies from New England, New Jersey, and New York. NESCAUM and its sister organization—the Northeast States Center for a Clean Air Future (NESCCAF)—provide technical assistance, research, and policy analysis to help the Northeast states develop and promote cost-effective clean air solutions necessary to enhance the quality of life of their citizens. Prior to joining NESCAUM in May 2002, Ken served as New Hampshire's air director, helping to make New Hampshire a national leader in reducing air pollution, including the first "4–Pollutant" bill for power plants and the first Greenhouse Gas Emissions Reduction Registry. Ken also served as a member of the U.S. Delegation negotiating an Ozone Annex to the U.S.–Canada Air Quality Agreement and during G8 environmental negotiations in Japan, and testified before Congress on several air quality issues.

Before joining the New Hampshire Department of Environmental Services (NHDES) in 1995, Ken was Vice President of the Business & Industry Association of New Hampshire (BIA), representing the State's business community on environmental, energy, and telecommunications matters in legislative and regulatory forums. Ken holds a B.S. in Mathematics from MIT and MBA and M.Ed. degrees from the University of New Hampshire. Ken and his family reside in Meredith, New Hampshire.

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Northeast States for Coordinated Air Use Management

Connecticut Bureau of Air Management, Anne Gobin, Acting
Maine Bureau of Air Quality Control, James Brooks
Massachusetts Bureau of Waste Prevention, Barbara Kwetz
New Hampshire Air Resources Division, Robert Scott, Acting
New Jersey Division of Air Quality, William O'Sullivan
New York Division of Air Resources, David Shaw, Acting
Rhode Island Office of Air Resources, Stephen Majkut
Vermont Air Pollution Control Division, Richard Valentinetti

November 21, 2003

Hon. Vern Ehlers, Chairman
Subcommittee on Environment, Technology and Standards
Committee on Science
United States House of Representatives
Washington, DC 20515

Re: Mercury Technology Hearing, November 5, 2003

Dear Rep. Ehlers:

Please be advised that since states direct some of their 105 money under the Clean Air Act to the Northeast States for Coordinated Air Use Management (NESCAUM), and because NESCAUM has had contracts with EPA on other issues, NESCAUM has received federal money. However, NESCAUM received no federal money related to NESCAUM's recent report ***Mercury Emissions from Coal Fired Power Plants: The Case for Regulatory Action*** which was the subject of my testimony before the Subcommittee on November 5, 2003.

Thank you also for the opportunity to provide further comment in response to questions that were asked at the hearing. There were several questions relating to the extent to which mercury deposition is the result of certain man-made sources and whether deposition in the U.S. is coming from domestic sources or from mercury that has been in the atmosphere for some time and may have originated outside of the U.S. The EPA, in a modeling analysis that was done for the 1997 ***Mercury Study Report to Congress***, estimated that about 60% of mercury deposited in the U.S. comes from current, domestic anthropogenic sources. The remaining 40% is from a combination of natural sources, foreign man-made sources, and mercury previously emitted from U.S. man-made sources, deposited, and now being re-emitted through natural processes. Among current U.S. man-made sources, about 40% of mercury emissions are from coal-fired electric power plants.

EPRI has done an analysis, which Dr. George Offen mentioned in response to a question, that looks at the percent of deposition at Mercury Deposition Network sites that originated as U.S. utility emissions and other U.S. sources. Utilities account for 20% or less of the deposition at these sites, and all U.S. sources account for between about 5% to 65% of the deposition and less than 40% at most of these deposition network sites. This finding is consistent with Dr Krabbenhoft's testimony. The deposition network sites are mostly very remote and far from sources of mercury emissions. As Dr Krabbenhoft testified, in the case of mercury deposited in remote locations that are far from sources of emissions, the contribution from globally distributed sources is relatively more important. At places that are nearer to emissions sources, the influence of local sources predominates. This is very consistent with result that EPA found in its ***Mercury Study Report to Congress***. In that study, EPA found that a single medium or large sized power plant is the dominant source of mercury contamination in waters up to 10 kilometers away.

Finally, some reflection concerning the state of today's mercury control technology vis-à-vis the state of sulfur dioxide controls in the early 1990s and the state of NOx controls in the mid-1990s may be enlightening. As Dr. Offen testified at the hearing, early control technologies for removing sulfur emissions from power plants was not well understood, which led to some situations where control technology installations had to be removed and replaced. Controls for nitrogen oxide emissions were substantially more advanced in the early to mid-1990s, with applications at power plants Europe and at pilot U.S. sites, but there was still vigorous – if inaccurate – opposition to mandating them, citing commercial availability concerns. In today's case with mercury, however,

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we have full scale commercial tests underway, a clearly transferable technology operating on other combustion facilities (e.g., municipal waste combustors), several near-term technologies with tests underway, and a host of new control technology developments coming out of the laboratories. In neither the sulfur nor NOx cases had such a broad control technology industry sprung up. Unlike the situation with sulfur or NOx, in the case of mercury, the absence of a regulatory driver is likely to kill an emerging industry that is already well underway toward commercialization in the compliance timeframes expected under EPA's Mercury MACT rule.

Thank you again for the opportunity to provide testimony at the November 5 hearing, as well as this additional input.

Sincerely,

Kenneth A. Colburn

Kenneth A. Colburn
Executive Director

Appendix 2:

Additional Material for the Record

NESCAUM
Northeast States for Coordinated Air Use Management

November 21, 2003

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Thank you again for the opportunity to provide testimony at the November 5 hearing, as well as this additional input.

Sincerely,

Kenneth A. Colburn

Kenneth A. Colburn
Executive Director

ELECTRIFY THE WORLD

EPRI

Fax: 202-225-4438
PAGE 1 OF 10

January 8, 2004

Mr. Adam Shampaine
U. S. House of Representatives
Committee on Science
Suite 2320 Rayburn House Office Building
Washington, DC 20515-6301

Dear Mr. Shampaine:

Subject: Review of November 5, 2003 testimony transcript

Per Chairman Ehlers' December 8, 2003 request, I have reviewed the transcript of my portion of the hearing and request the changes noted in the attached pages.

Per my offer at the Hearing, documented on page 70 of the transcript, I am also sending you a 2-page summary of a paper written by an EPRI contractor that describes our ability to model the relationship between mercury emissions and deposition. Tomorrow, I will e-mail you the paper as well as a Research Brief on a report that presents the results of a study on the cost and effectiveness of reducing mercury exposure to sensitive populations. That study relied, in part, on this transport model.

Once again, I would like to thank the Subcommittee on Environment, Technology and Standards for giving EPRI the opportunity to testify on the findings of our mercury control research. If you or any members of the Subcommittee or staff have any further questions about my testimony, the added material being submitted, or other aspects of the mercury question, please do not hesitate to contact me.

Sincerely,

George R. Offen

George R. Offen
Sr. Technical Leader
Emissions/Combustion Product Management

Enclosures

c: John Novak (EPRI – Washington, DC)

MODELING THE ATMOSPHERIC FATE AND TRANSPORT OF MERCURY OVER NORTH AMERICA*

Christian Seigneur, et al.
Atmospheric & Environmental Research, Inc., 2682 Bishop Drive, Suite 120, San Ramon, CA 94583

Abstract

A multi-scale modeling system that consists of a global cycling model and a continental-scale model, TEAM, is applied to simulate the fate and transport of mercury over North America. The performance of the modeling system is shown to be satisfactory. TEAM is used to simulate various emission control scenarios. The global background is calculated to contribute on average more than 70% to mercury deposition in the United States. Three different coal-fired power plant emission scenarios are simulated.

Model Performance Evaluation

The modeling system was evaluated against available monitoring data. A comparison of annual wet deposition fluxes of mercury simulated by TEAM with data from the Mercury Deposition Network (MDN) showed a coefficient of determination (r^2) of 0.51, a normalized absolute error of 24%, and a normalized bias of 4%. A comparison of observed and simulated wet deposition fluxes of mercury is shown in Figure 2. These results show some slight improvement over previous model performance evaluation results.

* Presented at the *International Conference on Air Quality III*, Arlington, VA September 2002

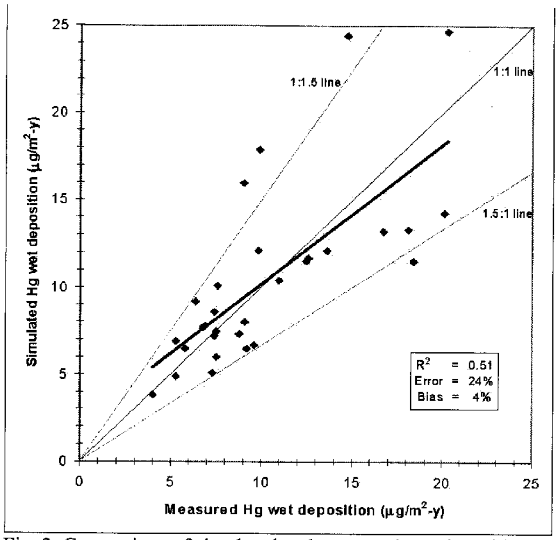

Fig. 2. Comparison of simulated and measured wet deposition fluxes of mercury at MDN sites in 1998.

Conclusion

A global/continental modeling system was used to investigate the effect of various emission scenarios on mercury deposition in the United States. The global background was shown to contribute 73% to mercury deposition in the United States on average. {*Additional conclusions are presented on scenario analyses; these are not included here as they go beyond the question of modeling capability discussed during the Hearing.*}

MODELING THE ATMOSPHERIC FATE AND TRANSPORT OF MERCURY OVER NORTH AMERICA

Christian Seigneur*, Krish Vijayaraghavan, Kristen Lohman and Prakash Karamchandani
Atmospheric & Environmental Research, Inc., 2682 Bishop Drive, Suite 120, San Ramon, CA 94583

Courtney Scott
Atmospheric & Environmental Research, Inc., 131 Hartwell Avenue, Lexington, MA 02421

ABSTRACT

A multiscale modeling system that consists of a global cycling model and a continental-scale model, TEAM, is applied to simulate the fate and transport of mercury over North America. The performance of the modeling system is shown to be satisfactory. TEAM is used to simulate various emission control scenarios. The global background is calculated to contribute on average more than 70% to mercury deposition in the United States. Three different coal-fired power plant emission scenarios are simulated.

INTRODUCTION

The origin of atmospheric mercury that is deposited to watersheds in the United States is currently poorly known. The relative contributions of local, regional and global anthropogenic sources as well as natural sources of mercury are likely to vary across the United States and it is important to characterize them to assess the likely efficiency of emission control strategies on the atmospheric deposition of mercury. We present here an analysis of the atmospheric fate and transport modeling of mercury using a multiscale modeling system that simulates the global cycling of mercury as well as its fate and transport over North America for an entire year. This modeling system includes a global chemical transport model (CTM) and a continental model, TEAM[1]. It has been previously applied to estimate the relative contributions of regional and global sources to mercury deposition in New York State[2] and the contribution of Wisconsin sources and midwestern U.S. power plants on mercury deposition in Wisconsin[3]. This modeling system is updated to reflect the current state of the science and it is evaluated with available data. It is applied here to investigate the effect of various scenarios for coal-fired power plant emissions on mercury deposition in the contiguous United States.

DESCRIPTION OF THE MODELING SYSTEM

The modeling system used in this study consists of two nested models: (1) a global CTM and (2) a continental CTM. The global CTM provides the boundary conditions for the continental CTM. The global CTM is run until steady state is achieved between emissions of mercury into the atmosphere and deposition to the earth. The continental CTM is run for one

year, 1998 in this study. The atmospheric emissions and chemistry of mercury are the same in both models. Seigneur et al.[1] describe this modeling system and its initial application. For this study, the atmospheric chemical mechanism and the emission inventory were updated.

Emissions

The emission inventory used in this study is based on that of Seigneur et al.[1] with the following updates.

For the U.S. emission inventory, some source categories (coal-fired power plants and chlor-alkali facilities) were updated and one source category (mobile sources) was added. For coal-fired power plants, a new emission inventory provided by EPRI[4] was used. For chlor-alkali plants, a Wisconsin facility was added. That facility had been overlooked in the previous inventory because its emissions had not been reported in the 1998 Toxic Release Inventory (TRI); nevertheless, this facility is still in operation. Mobile sources contribute to anthropogenic emissions of mercury and the emission value provided by the U.S. Environmental Protection Agency (EPA) was used. These mobile source emissions were provided on a county-level basis and distributed uniformly over each county. This U.S. anthropogenic mercury emission inventory is summarized by source category in Table 1.

Table 1. Anthropogenic Hg Emissions in the North American Domain (Mg/y).

Source Category	United States	Southern Canada	Northern Mexico	Total
Electric utilities	41.5	1.3	9.9	52.7
Waste incineration	28.8	3.4		32.2
Residential, commercial, and industrial coal burning	12.8			12.8
Mining	6.4	0.3		6.7
Chloralkali facilities	6.7	.05		6.8
Other sources	36.8	9.6	23.6	70.0
Total	133.0	14.7	33.5	181.2

No changes were made to global anthropogenic mercury emissions besides those listed above for the United States.

Background emissions consist of natural emissions and re-emissions of previously deposited mercury. Since it is not possible to differentiate between natural and anthropogenic mercury after it has been emitted, re-emissions must necessarily include both natural and

anthropogenic mercury. The following changes were made to background mercury emissions. One source category, volcanoes, was added to the inventory of natural emissions. This source category was assumed to amount to 90 Mg/yr and was spatially distributed according to the location of active volcanoes[5, 6]. Emissions from terrestrial mercuriferous zones total 500 Mg/yr globally in our inventory. This value corresponds to about 10 Mg/yr for the state of Nevada, which is consistent with the estimate of 14 Mg/yr derived by Zehner and Gustin[7] from experimental data. Other mercury background emissions from land surfaces (i.e., re-emissions) were selected to be 1670 Mg/yr, i.e., about 25% of total global mercury emissions[1]. Emissions from oceans (2000 Mg/yr)[1] include both natural emissions (474 Mg/yr) and re-emissions (1526 Mg/yr); this distribution is based on current global mercury emissions being three times the pre-industrial (i.e., natural) emissions.

Atmospheric Chemical Mechanism

The atmospheric chemical mechanism was updated for this study to reflect recent laboratory data on chemical kinetics and thermodynamics. The gas-phase reaction of Hg(0) with OH radicals was added[8]. The product was assumed to be $Hg(OH)_2$. The kinetic rate constant is 8×10^{-14} cm^3 $molec^{-1}$ s^{-1}. The thermodynamic equilibrium constants for the formation of the complexes $HgSO_3$ and $Hg(SO_3)_2^{2-}$ in the aqueous phase were updated based on the work of van Loon et al.[9] The kinetics of the gas-phase reaction of Hg(0) with Cl_2 was updated based on the recent laboratory data of Ariya et al.[10] The full chemical kinetic mechanism is described elsewhere[1, 11].

Global Mercury Chemical Transport Model

The formulation of the global Hg model has been described in detail by Shia et al.[11] and Seigneur et al.[1] We present here an overview and highlight the recent changes made to the model formulation.

The global Hg model is based on the three-dimensional (3-D) CTM developed at the Goddard Institute for Space Studies (GISS), Harvard University, and the University of California at Irvine. The 3-D model provides a horizontal resolution of 8° latitude and 10° longitude and a vertical resolution of nine layers ranging from the Earth's surface to the lower stratosphere. Seven layers are in the troposphere (between the surface and ~12 km altitude), and two layers are in the stratosphere (between ~12 km and 30 km altitude).

Transport processes are driven by the wind fields and convection statistics calculated every 4 hours (for 1 year) by the GISS general circulation model[12]. This 1-year data set is used repeatedly for multiyear simulations until steady state is achieved.

The Hg transformation processes include gas-phase transformations, gas/droplet equilibria, ionic equilibria, solution/particle adsorption equilibrium, and aqueous-phase transformations as described above. The chemical species reacting with Hg were input to the model as described by Seigneur et al.[1]

The dry deposition velocity of Hg(II) was selected to be 0.25 cm s^{-1} for Hg(II). The dry deposition velocity of Hg(0) was selected to be 0.01 cm s^{-1} over land and, because of its low solubility, zero over the oceans. The Hg(p) deposition velocity was selected to be 0.1 cm s^{-1}

over land and 0.01 cm s^{-1} over water; these values are typical for fine particles. Wet deposition is calculated using the cloud droplet chemical concentrations and the precipitation patterns. For below-cloud scavenging, we assumed no scavenging of Hg(0), 100% scavenging of Hg(II), and 50% scavenging of Hg(p).

Continental Mercury Chemical Transport Model

The formulation of the continental CTM, TEAM, has been described in detail by Pai et al.[13] and Seigneur et al.[1] We present here an overview of the model and point out the major modifications made since its initial application.

TEAM is a 3-D Eulerian model that simulates the transport, chemical and physical transformations, wet and dry deposition of Hg species. In this application to North America, the horizontal grid resolution is 100 km, and the vertical resolution consists of six layers from the surface to 6 km altitude with finer resolution near the surface (the layer interfaces are at 60, 150, 450, 850, and 2000 m). Transport processes include transport by the 3-D mean wind flow and dispersion by atmospheric turbulence. The module that simulates the chemical and physical transformations of Hg was described above and is the same module as that used in the global model. Three Hg species, Hg(0), Hg(II), and Hg(p) are simulated. Hg(II) actually consists of several chemical species in the gas phase and in cloud droplets; Hg(II) can also adsorb to PM.

Wet deposition is simulated only for Hg(II) and Hg(p) since Hg(0) is relatively insoluble. The wet deposition flux is calculated as the product of the cloud droplet concentration of the Hg species and the precipitation amount. Scavenging of these Hg species by rain below the cloud (washout) is treated as a transient process using scavenging coefficients that depend on precipitation intensity as described by Seigneur et al.[1]

Dry deposition is simulated using the resistance transfer approach. For Hg(0), background emissions and dry deposition are assumed to balance each other over North America. This assumption is justified by the fact that the atmospheric lifetime of Hg(0) (about 1 year) greatly exceeds its residence time (a few days) within the North American domain. For Hg(II), the dry deposition characteristics are assumed to be similar to those of nitric acid (HNO_3) because these two gases have similar solubility. Dry deposition velocities calculated by TEAM for Hg(II) and Hg(p) over various surface types (forest, agricultural land, and water) were presented by Pai et al.[12] with the updates described by Seigneur et al.[1]

The simulated total (i.e., both wet and dry) mercury deposition is depicted in Figure 1.

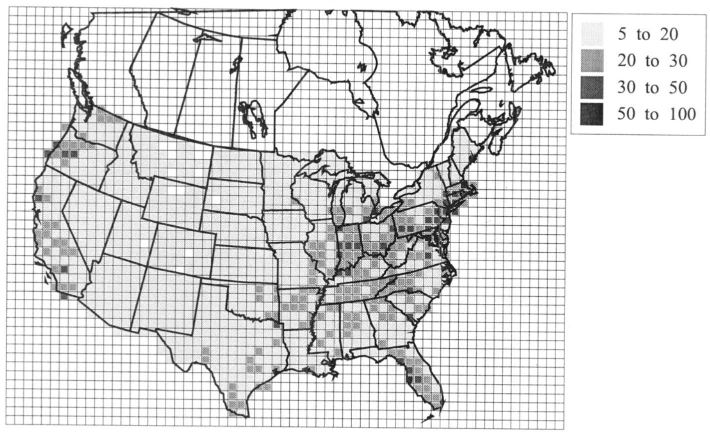

Fig. 1. Simulated total deposition (μg/m^2-y) of mercury for 1998 in the contiguous United States, base case emissions.

Areas of high deposition on the west coast are due primarily to high precipitation and are governed by the upwind boundary condition. Other areas of high deposition occur primarily in the northeastern United States. The model grid cell with the highest mercury deposition corresponds to a combination of high local emissions (e.g., Baltimore municipal waste combustor), regional contributions, and global background.

Model Performance Evaluation

The modeling system was evaluated against available monitoring data. A comparison of annual wet deposition fluxes of mercury simulated by TEAM with data from the Mercury Deposition Network (MDN) showed a coefficient of determination (r^2) of 0.51, a normalized absolute error of 24%, and a normalized bias of 4%. A comparison of observed and simulated wet deposition fluxes of mercury is shown in Figure 2. These results show some slight improvement over previous model performance evaluation results[14].

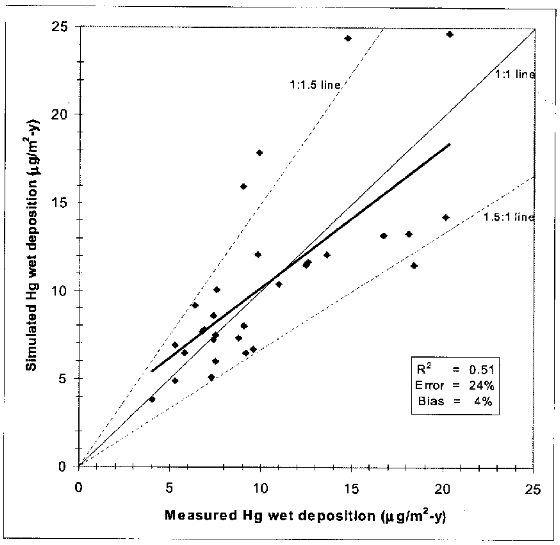

Fig. 2. Comparison of simulated and measured wet deposition fluxes of mercury at MDN sites in 1998.

EMISSION SCENARIOS

Effect of the Global Background

A TEAM simulation was conducted with no North American emissions within the modeling domain. Thus, mercury deposition within the contiguous United States was due solely to the boundary conditions, i.e., the global background, consisting of the sum of anthropogenic new emissions from outside North America, re-emitted anthropogenic and natural emissions, and new natural emissions. The results are presented in Figure 3 as the percentage contribution of the global background to total mercury deposition in the United States. On average, the global background contributed 73% to mercury deposition in the United States.

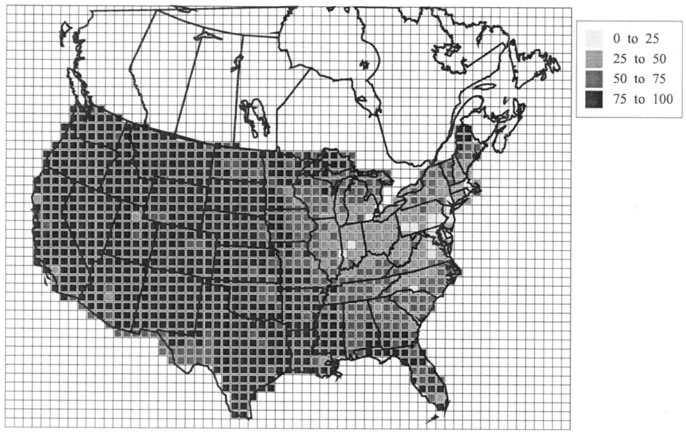

Fig. 3. Simulated contribution (%) of the global background to total deposition of mercury in the contiguous United States.

Power Plant Emission Scenarios

The effects of various scenarios for reducing mercury emissions from coal-fired power plants in the United States were simulated. The three emission scenarios are the following:

- Scenario 1 (No subcategorization by fuel or controls)

	Stack Limit	Overall Reduction
All coal-fired power plants except fluidized bed combustion (FBC)	2.2 lb/10^{12} Btu	71%
FBC	2.0 lb/10^{12} Btu	91%

- Scenario 2 (Coal rank subcategorization)

	Stack Limit	Overall Reduction
Bituminous coal	2.2 lb/10^{12} Btu	73%
Subbituminous coal	4.2 lb/10^{12} Btu	31%
Lignite coal	6.5 lb/10^{12} Btu	47%
FBC	2.0 lb/10^{12} Btu	91%

- Scenario 3 (Coal rank and process subcategorization[(a)])

	Stack Limit	Overall Reduction
Bituminous coal – Hot temperature (no scrubbers)	3.7 lb/10^{12} Btu	55%
Bituminous coal – Saturated	2.2 lb/10^{12} Btu	63%
Bituminous coal – Wet scrubber	3.2 lb/10^{12} Btu	62%
Subbituminous coal	4.2 lb/10^{12} Btu	31%
Lignite coal	6.5 lb/10^{12} Btu	47%
FBC	2.0 lb/10^{12} Btu	91%

(a) Process subcategories are based on the flue gas temperature at control device exit; designation of control devices is intended as a descriptor of this temperature criterion.

These scenarios were based on proposals placed before the U.S. EPA Utility MACT Working Group[15]. The emissions of the continental North American domain were modified accordingly and a TEAM simulation was conducted for each scenario. Note that the secondary effect of these emission scenarios on the upwind boundary condition of the continental domains was not taken into account because U.S. power plant emissions account for less than 1% of total global emissions.

The results for Scenario 1 are presented in Figure 4 in terms of percentage differences with respect to the base case simulation presented in Figure 1. Most of the United States shows changes in total mercury deposition that are less than 10%. Only twelve grid cells located in the eastern United States show changes that exceed 20%.

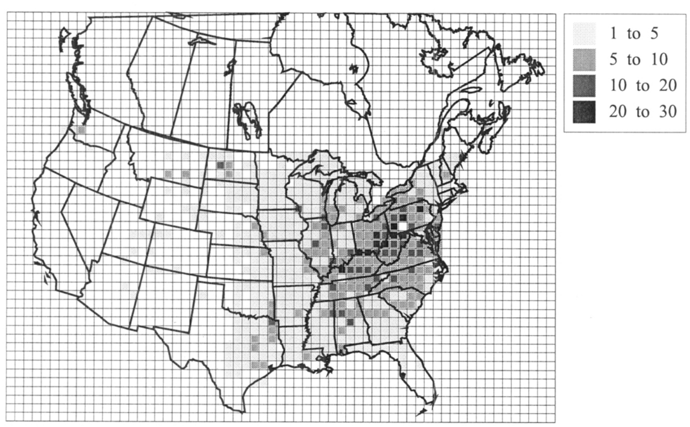

Fig. 4. Simulated percentage change in total deposition of mercury from the base case due to Scenario 1.

One should note, however, that the local and regional impacts of power plant emissions may be overestimated by this model[14]. There seems to be some evidence of reduction of Hg(II) to Hg(0) in power plant plumes from various experimental studies. First, the MDN data along a west-to-east transect from Minnesota to Pennsylvania show no significant spatial gradient in Hg annual wet deposition fluxes although the Ohio Valley includes several large Hg emission sources located, under prevailing wind conditions, upwind of Pennsylvania. Second, the University of North Dakota Energy and Environmental Research Center and Frontier Geosciences, Inc. conducted experiments where the exhaust flue gases from a coal-fired power plant stack were sampled, diluted and analyzed in a Teflon-lined dispersion chamber. These experiments showed a lower Hg(II)/Hg(0) ratio in the chamber than in the stack[16]. Third, ambient sampling of Hg species [Hg(II), Hg(0), and Hg(p)] downwind of coal-fired power plants in the Atlanta region suggests that the Hg(II)/Hg(0) ratio at the downwind location is lower than the Hg(II)/Hg(0) ratio estimated from the Information Collection Request (ICR) data for the stack emissions[17]. Furthermore, modeling of these power plant plumes indicates that current models do not account for this change in the Hg(II)/Hg(0) ratio in the plumes[18]. Because Hg(II) reduction may be underestimated in current models, Hg wet deposition due to local and regional sources is likely to be overestimated.

The results of Scenarios 2 and 3 are presented in terms of percentage differences with respect to those of Scenario 1 in Figures 5 and 6. It appears that the subcategorization of the power plants by coal type or by type of emission control equipment has little further effect on mercury deposition.

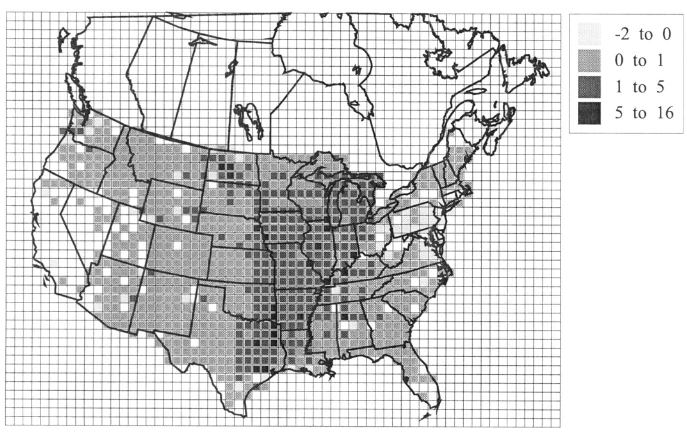

Fig. 5. Simulated percentage change in total deposition of mercury between Scenario 2 and Scenario 1.

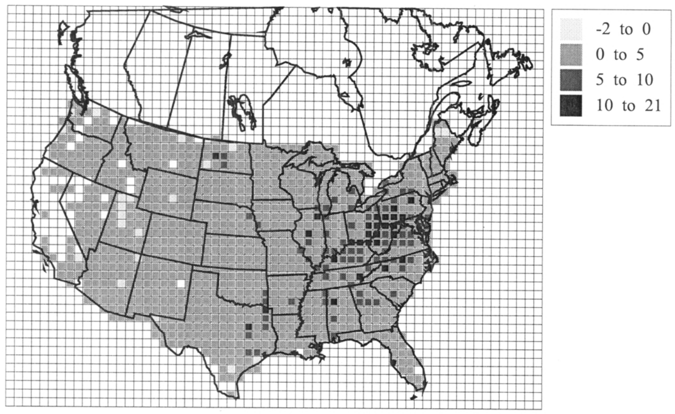

Fig. 6. Simulated percentage change in total deposition of mercury between Scenario 3 and Scenario 1.

CONCLUSION

A global/continental modeling system was used to investigate the effect of various emission scenarios on mercury deposition in the United States. The global background was shown to contribute 73% to mercury deposition in the United States on average. Three scenarios for reduction of coal-fired power plant emissions were simulated. For Scenario 1 that did not include any subcategorization of the power plants, most of the United States shows changes in total mercury deposition that are less than 10%. Subcategorization of power plants by coal rank and process was shown to have little further effect on mercury deposition.

ACKNOWLEDGMENTS

This project was conducted under contract EP-P9096/C4576 with EPRI, Palo Alto, California. We thank the EPRI project manager, Dr. Leonard Levin, for his continuous support.

REFERENCES

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Global Source Attribution for Mercury Deposition in the United States

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A multiscale modeling system that consists of a global chemical transport model (CTM) and a nested continental CTM was used to simulate the global atmospheric fate and transport of mercury and its deposition over the contiguous United States. The performance of the CTMs was evaluated against available data. The coefficient of determination (r^2) for observed versus simulated annual mercury wet deposition fluxes over North America was 0.50 with average normalized error and bias of 25% and 11%, respectively. The CTMs were used to conduct a global source attribution for selected receptor areas. Three global emission scenarios were used that differed in their distribution of background emissions among direct natural emissions and re-emissions of natural and anthropogenic mercury. North American anthropogenic sources were calculated to contribute only from 25 to 32% to the total mercury deposition over the continental United States. At selected receptors, the contribution of North American anthropogenic emissions ranges from 9 to 81%; Asian anthropogenic emissions were calculated to contribute from 5 to 36%; natural emissions were calculated to contribute from 6 to 59%.

Introduction

The origin of atmospheric mercury that is deposited to watersheds in the United States is currently poorly understood. The relative contributions of local, regional, and global anthropogenic sources as well as natural sources of mercury are likely to vary across the United States, and it is important to characterize them to assess the likely efficacy of future emission control strategies on the atmospheric deposition of mercury. We present here an analysis of source contributions to mercury dry and wet deposition in the contiguous United States. Our analysis is based on the atmospheric fate and transport modeling of mercury using a multiscale modeling system that simulates the global cycling of mercury as well as its fate and transport over North America for an entire year. This modeling system includes a global chemical transport model (CTM) and a continental CTM, TEAM (*1*). Such an approach is desirable because mercury is a global pollutant with an average atmospheric lifetime on the order of a year. Therefore, the upwind boundary concentrations of mercury species are quite influential for modeling the atmospheric fate and transport of mercury at continental and regional scales (*2*). Because there is a paucity of data to specify such boundary conditions, particularly aloft, it is more reliable to obtain such boundary conditions from a global simulation, contingent upon satisfactory performance of the global CTM. Thus, the global CTM provides spatially distributed and temporally resolved fields of background mercury species concentrations, and the continental CTM uses these background concentrations along with the mercury emissions within the continental domain to calculate mercury fate and transport at a spatial resolution finer than that of the global CTM. This modeling system was updated here to reflect the current state of the science and evaluated with available monitoring data before its application to the analysis of source–receptor relationships.

We present first a brief description of the modeling system including the recent updates made to the atmospheric chemical transformations of mercury. Next, we describe the base emission inventory and two alternative inventories used in this study to bound the uncertainties associated with the background emissions (i.e., natural emissions and re-emissions). Then, we evaluate the performance of this modeling system with available data on mercury ambient concentrations and wet deposition fluxes. Finally, the modeling system is used to perform a source attribution of mercury deposition at selected receptors across the United States. Earlier work presented a similar, but more limited, analysis for mercury deposition in New York state (*3*). The present analysis highlights the large variations that occur in the various global source contributions to mercury deposition across the North American continent.

Description of the Modeling System

The modeling system used in this study consists of two nested models: a global CTM that is run until steady state is achieved between emissions of mercury into the atmosphere and deposition to the earth and a continental CTM that is run for one year, 1998 in this study. The atmospheric emissions and chemistry of mercury are the same in both models. Seigneur et al. (*1*) have described this modeling system and its initial application. For this study, the atmospheric chemical mechanism and some other aspects of the model formulation were updated from those used by Seigneur et al. (*1*) as described below.

Atmospheric Chemical Mechanism. The atmospheric chemical mechanism is based on the work of Seigneur et al. (*4*), with updates described by Shia et al. (*5*) and Seigneur et al. (*1*). This mechanism was included in a recent model intercomparison (*6*). It was updated for this study to reflect recent laboratory data on chemical kinetics and thermodynamics. Those updates are the following.

The gas-phase reaction of Hg(0) with OH radicals was added (*7*). The product was assumed to be $Hg(OH)_2$. The kinetic rate constant is 8×10^{-14} cm^3 $molecule^{-1}$ s^{-1}. The thermodynamic equilibrium constants for the formation of the complexes $HgSO_3$ and $Hg(SO_3)_2^{2-}$ in the aqueous phase were updated on the basis of the work of van Loon et al. (*8*). The kinetics of the gas-phase reaction of Hg(0) with Cl_2 was updated on the basis of the recent laboratory data of Ariya et al. (*9*).

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The products of the gas-phase reactions vary among HgO, $Hg(OH)_2$, and $HgCl_2$. HgO can be in the gas phase or the particulate phase because its saturation vapor pressure is low, 9×10^{-17} atm at 25 °C (*10*). For an ozone concentration of 40 ppb, it takes ~4.5 h to convert enough Hg(0) to reach the HgO saturation vapor pressure. HgO is very soluble in water, with a Henry's law constant of 2.69×10^{12} M atm^{-1} at 25 °C (*10*), and HgO particles are likely to be very efficiently scavenged by cloud droplets. Thus, in the presence of clouds, HgO is nearly totally present in the aqueous phase, where it rapidly dissociates to Hg^{2+} (*11*). Then, Hg^{2+} reacts with Cl^-, OH^-, and SO_3^{2-} to form new species. $HgCl_2$ and $Hg(OH)_2$ have saturation vapor pressures that exceed their atmospheric concentrations and consequently do not condense to the particulate phase. Both $HgCl_2$ and $Hg(OH)_2$ are quite soluble and partition between the gas phase and the aqueous phase in the presence of clouds. Therefore, it is not necessary to specify the end products of the oxidation reactions of Hg(0) in the chemical kinetic mechanism because, in the presence of clouds, these species dissolve in cloud droplets where the chemical speciation of Hg(II) is governed by aqueous-phase and gas/droplet equilibria.

Some aqueous-phase equilibria are neglected in this chemical mechanism. Those include the equilibria leading to the formation of $HgCl^+$, $HgCl_3^-$, $HgCl_4^-$, HgOHCl, and $HgOH^+$. Among the various mercury chloride salts, $HgCl_2$ dominates at pH values typical of clouds. Other species may dominate in aqueous particles where pH values can be very low, but atmospheric chemical reactions in aerosols do not contribute significantly on global and regional scales to the total mercury mass budget because of the low liquid water content of particles; atmospheric particles may, however, affect the chemical speciation of mercury in specific cases such as the influence of sea-salt particles in the marine boundary layer (*12*). Therefore, only $HgCl_2$ is relevant to mercury aqueous chemistry for regional/global scales, and it is appropriate here to neglect the other chloride species. Under most conditions, the equilibria favor $HgCl_2$ over $Hg(OH)_2$ and other mercury hydroxide species. These latter species become important only when HCl concentrations become very low. A background HCl surface concentration of 0.7 $\mu g/m^3$ (*13*) is used in the global CTM and in TEAM and, therefore, the mercury hydroxide species can be neglected. $Hg(OH)_2$ is included in the mechanism for sensitivity simulations where HCl concentrations are selected to be very low or even zero.

Global Mercury Chemical Transport Model. The formulation of the global Hg model has been described in detail elsewhere (*1, 5*). We present here an overview and highlight the recent changes made to the model formulation.

The global Hg model is based on the three-dimensional (3D) CTM developed at the Goddard Institute for Space Studies (GISS), Harvard University, and the University of California at Irvine. The 3D model provides a horizontal resolution of 8° latitude and 10° longitude and a vertical resolution of nine layers ranging from the Earth's surface to the lower stratosphere. Seven layers are in the troposphere (between the surface and ~12 km altitude), and two layers are in the stratosphere (between ~12 and 30 km altitude).

Transport processes are driven by the wind fields and convection statistics calculated every 4 h (for 1 year) by the GISS general circulation model (*14*). This 1-year data set is used repeatedly for multiyear simulations until steady state is achieved.

The Hg transformation processes include gas-phase transformations, gas/droplet equilibria, ionic equilibria, solution/particle adsorption equilibrium, and aqueous-phase transformations as described above. The chemical species reacting with Hg are input to the model as described by Seigneur et al. (*1*).

The dry deposition velocity of Hg(II) was selected by analogy with that of nitric acid because of similar solubility. Measurements of nitric acid dry deposition velocities are in the range of 0.06–5 cm/s (*15*) with a mean value of 0.5 cm/s (*16*). We selected an average dry deposition velocity of 0.5 cm/s. The dry deposition velocity of Hg(0) has been estimated to be 0.09 cm/s under typical summer conditions over a forest canopy in Tennessee (*17*). Model simulations using a bi-directional atmosphere–surface exchange model led to a range of 0.02–0.15 cm/s, with an average value of 0.06 cm/s over plant canopies (*18*). However, experimental data suggest that the uptake of Hg(0) by vegetation occurs only when the atmospheric concentration of Hg(0) exceeds a threshold value referred to as the compensation point (*19*). For white oak, red maple, Norway spruce, and yellow poplar, the compensation points were estimated to be in the range of 10–25 ng/m^3, that is, above typical background annual average Hg(0) concentrations. Therefore, the deposition velocities reported above should be seen as upper limits because no Hg(0) deposition may occur when Hg(0) ambient concentrations are below the vegetation compensation points. Consequently, we selected the Hg(0) dry deposition velocity to be 0.01 cm/s over land and, because of its low solubility, 0 over the oceans. The Hg(p) deposition velocity was selected to be 0.1 cm/s over land and 0.01 cm/s over water; these values are typical for fine particles (e.g., assuming a particle diameter of 0.3 μm and a surface roughness of 0.1–1 m over land and 0.1–1 cm over water) (*20*). The value over land is consistent with the Hg(p) deposition velocity of 0.1 cm/s estimated for a typical summer day over a forest canopy in Tennessee (*17*).

Wet deposition is calculated using the cloud droplet chemical concentrations and the precipitation patterns. For below-cloud scavenging, we assumed no scavenging of Hg(0), 100% scavenging of Hg(II), and 50% scavenging of Hg(p). The Hg emissions consisted of Hg(0), Hg(II), and Hg(p) gridded emissions for anthropogenic and background sources as described below.

Continental Mercury Chemical Transport Model. The formulation of the continental CTM, TEAM, has been described in detail elsewhere (*1, 21*). We present here an overview of the model and point out the major modifications made since its initial application.

TEAM is a 3D Eulerian model that simulates the transport, chemical and physical transformations, and wet and dry depositions of Hg species. In this application to North America, the horizontal grid resolution is 100 km, and the vertical grid consists of six layers from the surface to 6 km altitude with finer resolution near the surface (the layer interfaces are at 60, 150, 450, 850, and 2000 m). Transport processes include transport by the 3D mean wind flow and dispersion by atmospheric turbulence. The module that simulates the chemical and physical transformations of Hg described above is the same module as that used in the global model. Three Hg species, Hg(0), Hg(II), and Hg(p), are simulated. Hg(II) actually consists of several chemical species in the gas phase and in cloud droplets; Hg(II) can also adsorb to particulate matter (PM) in droplets.

Wet deposition is simulated only for Hg(II) and Hg(p) because Hg(0) is relatively insoluble. The wet deposition flux is calculated as the product of the cloud droplet concentration of the Hg species and the precipitation amount. Scavenging of these Hg species by rain below the cloud (washout) is treated as a transient process using scavenging coefficients that depend on precipitation intensity (*1*).

Dry deposition is simulated using the resistance transfer approach. The deposition process is simulated as a series of three mass transfer steps: (1) turbulent transport from the bulk atmosphere to near the surface, (2) diffusion through a laminar layer near the surface, and (3) uptake of the gas

TABLE 1. Anthropogenic Hg Emissions in the North American Domain (Mg/year)

source category	United States	southern Canada	northern Mexico	total	refs[a]
electric utilities	41.5	1.3	9.9	52.7	*22–25*
waste incineration	28.8	3.4	*b*	32.2	*25–28*
residential, commercial, and industrial coal burning	12.8	*b*	*b*	12.8	*25*
mining	6.4	0.3	*b*	6.7	*25, 29*
chlor-alkali facilities	6.7	0.05	*b*	6.8	*29, 30*
mobile sources	24.8	*b*	*b*	24.8	*31*
other sources	30.9	9.6	23.6	64.1	*1, 25*
total	**151.9**	**14.7**	**33.5**	**200.1**	

[a] See refs *1* and *25* for more detail on the development of the emission inventory. [b] Included in "other sources".

or particle by the surface. In the earlier formulation of TEAM, background emissions and dry deposition of Hg(0) were assumed to balance each other over North America. This assumption was justified by the fact that the atmospheric lifetime of Hg(0) (a few months) greatly exceeds its residence time (a few days) within the North American domain. In this current formulation, we explicitly treat the background emissions of Hg(0) and its dry deposition. The background emissions of Hg(0) include natural emissions from Mount St. Helen and from the mercuriferous areas of the western part of the domain (ranging from southern Canada to northern Mexico), as well as re-emissions of deposited mercury. We assumed that 50% of deposited mercury was re-emitted (see discussion of emissions below). For consistency with the global model, the dry deposition of Hg(0) was selected to be ~0.01 cm/s on average. For Hg(II), the dry deposition characteristics are assumed to be similar to those of nitric acid (HNO_3) because these two gases have similar solubilities. Dry deposition velocities calculated by TEAM for Hg(II) and Hg(p) over various surface types (forest, agricultural land, and water) are those used by Pai et al. (*21*) with the updates described by Seigneur et al. (*1*).

Emissions

North American Emissions. The North American anthropogenic mercury emission inventory is summarized by source category in Table 1. It is based on an earlier inventory (*1*). For the United States, some source categories (coal-fired power plants and chlor-alkali facilities) were updated and some source categories (mobile sources, landfills, and electric arc furnaces) were added. For coal-fired power plants, a new emission inventory provided by EPRI (*22*) was used. This inventory reflected the recent data on mercury coal content collected at all coal-fired power plants and stack measurements of speciated mercury conducted at >80 power plants as part of the U.S. Environmental Protection Agency (EPA) Information Collection Request (ICR) program. For chlor-alkali plants, a Wisconsin facility was added. That facility had been overlooked in the previous inventory because its emissions had not been reported in the 1998 Toxics Release Inventory (TRI) (*29*); nevertheless, this facility is still in operation. For mobile sources, the emission value (25 Mg/year) from the recent 1999 National Toxics Inventory (NTI) of the EPA (*31*) was used (an increase of 9 Mg/year from the earlier inventory). These mobile source emissions were obtained on a county-level basis and distributed uniformly over each county. Emissions from landfills (0.23 Mg/year) were distributed as area sources according to county data, and emissions from electric arc furnaces (0.014 Mg/year) were distributed according to their exact point source location. No changes were made to the Canadian and Mexican emission inventories.

Global Emissions. No changes were made to global anthropogenic mercury emissions besides those listed above for the United States. Anthropogenic emissions amount to 2143 Mg/year and consist of 246, 209, 176, 1138, 326, and 48 Mg/year for Africa, North America, Central and South America, Asia, Europe, and Oceania, respectively. One source category, volcanoes, was added to the inventory of natural emissions of Seigneur et al. (*1*). Natural emissions consist now of three source categories: mercury-enriched land areas, volcanoes, and oceans.

Direct emissions from mercury-enriched land areas amount to 500 Mg/year in our base inventory. They are uniformly distributed according to a global map of natural enrichment of mercury as reported in Figure 1 of Gustin et al. (*32*). As a check on this estimate, this value corresponds to ~10 Mg/year for Nevada when scaled by land area. This value is consistent with the estimate of 9.4 Mg/year derived by Zehner and Gustin (*33*) from experimental data (they assumed that 30% of mercury deposited—with a wet/dry deposition ratio of 1—was re-emitted).

Volcanic emissions were estimated to be 125 Mg/year for 1998. First, the activity of volcanoes was characterized (i.e., erupting and/or degassing) (*34*). Next, the emissions associated with eruption were estimated by obtaining volcano-specific information on the number of days of eruption during 1998 (*35*). Emission factors for eruption and degassing were obtained from Nriagu and Becker (*36*). This source category was then spatially distributed according to the location of those active volcanoes.

Emissions from oceans include direct emissions and re-emissions of natural and anthropogenic mercury. In our base inventory, emissions from oceans amount to ~2000 Mg/year. Mason and Sheu (*37*) recently estimated total emissions of mercury from oceans at 2600 Mg/year. However, they considered that a significant fraction of the Hg(0) emitted was rapidly oxidized to Hg(II) in the marine boundary layer and deposited back to the ocean. They estimated the total net flux out of the marine boundary layer to be 1460 Mg/year. Our global model accounts for some oxidation process that can occur within the marine boundary layer (aqueous oxidation by Cl_2); however, the coarse spatial resolution required by the global scale simulation does not allow for a sufficiently detailed representation of the processes occurring within the marine boundary layer. Therefore, it seems to be appropriate that our estimate of emissions from oceans lies within the range of the gross and net fluxes estimated by Mason and Sheu (*37*).

Emissions of mercury also occur during vegetation fires. Friedli et al. (*38, 39*) have reported laboratory and field experimental data. When those data are extrapolated to a global biomass inventory, estimates of mercury emissions from biomass burning range from ~100 to 800 Mg/year (*38*). Such emissions are likely to correspond to the re-emission of mercury previously deposited to the vegetation or the underlying soil. Therefore, we did not include a separate category for mercury emissions from fires in our global emission inventory because such emissions are assumed to be included in the re-emissions.

Re-emissions constitute the difference between the total emissions and the direct (both anthropogenic and natural) emissions (see below).

Emission Scenarios. The global mercury emission budget, T (Mg/y), can be expressed as

$$T = A_d + A_r + N_d + N_r \qquad (1)$$

where A_d represents the direct anthropogenic emissions, A_r represents the re-emissions of anthropogenic mercury, N_d

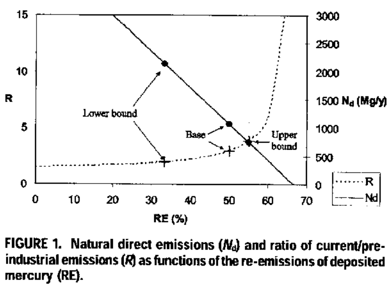

FIGURE 1. Natural direct emissions (N_d) and ratio of current/pre-industrial emissions (R) as functions of the re-emissions of deposited mercury (RE).

represents the direct natural emissions, and N_r represents the re-emissions of natural mercury. The ratio of current emissions to pre-industrial (i.e., natural) emissions, R, is then defined as follows:

$$R = T/(N_d + N_r) \tag{2}$$

The percentage of deposited mercury that is re-emitted, RE, is defined as follows:

$$\mathrm{RE} = 100 \times (A_r + N_r)/T \tag{3}$$

In our base scenario, we assume that current emissions are 3 times greater than pre-industrial emissions, that is, $R = 3$. Therefore, natural emissions are half of the anthropogenic emissions, that is, 1067 Mg/year (derived from an anthropogenic value of 2134 Mg/year prior to the update of the U.S. mobile sources, see Supporting Information), and total direct emissions are 3210 Mg/year. We also assume that half of deposited mercury (both natural and anthropogenic) is being re-emitted, that is, RE = 50%. Because the amount of mercury emitted must equal the amount deposited, re-emissions account for half of the total emissions.

There are some significant uncertainties in the estimates of background emissions, for example, the magnitude of natural emissions as well as the fraction of deposited mercury that is re-emitted. To address those uncertainties, we considered two alternative scenarios. We constrained the total global emissions and the direct anthropogenic emissions to the values listed above, that is, 6411 and 2143 Mg/year, respectively. Thus, background emissions amount to 4268 Mg/year to be distributed among direct natural emissions, re-emissions of natural mercury, and re-emissions of anthropogenic mercury. Figure 1 presents the direct natural emissions as a function of RE. Also shown in Figure 1 is the ratio of current emissions to pre-industrial emissions, R, as a function of RE. (See Supporting Information for more detail on the global emissions and the functions presented in Figure 1.)

Measurements of mercury concentrations in sediments and peat cores suggest that current mercury global concentrations are 1.5–12 times those of pre-industrial times (*40–45*). The most recent analyses are discussed below. The analysis of peat bog and lake sediments in Nova Scotia and New Zealand by Lamborg et al. (*42*) led those authors to estimate a ratio of current/pre-industrial deposition fluxes of ~4. Schuster et al. (*43*) analyzed ice-core samples in the Upper Fremont Glacier in Wyoming and estimated a ratio of 11. Bindler (*44*) sampled peat cores in south-central Sweden and estimated a ratio of at least 10. Roos-Barraclough and Shotyk (*45*) sampled peat cores at two nearby sites in Switzerland and estimated a ratio of 11–12.

When using such data to estimate the ratio of current and pre-industrial emissions, one assumes that the ratio of deposition fluxes can be applied to emissions. This is an approximation because anthropogenic emissions include gaseous Hg(II) and Hg(p), which are deposited closer to their source than Hg(0) and, therefore, may not enter the global background, and atmospheric concentrations of reactants such as O_3, SO_2, OH, and HO_2 have changed from pre-industrial times to current times.

Figure 1 shows that a value of $R > 6$ requires that >60% of deposited mercury be re-emitted. Also, a value of $R > 6$ leads to natural emissions of <400 Mg/year, which seems inconsistent with estimates of natural emissions from volcanoes (~100 Mg/year) and mercuriferous belts (~500 Mg/year). Therefore, estimates of a ratio of current/pre-industrial deposition fluxes of >6 may reflect a local or regional mercury deposition pattern and may not be representative of a globally averaged ratio of current emissions to pre-industrial emissions.

There is no comprehensive information on mercury re-emissions because this process is likely to depend on surface type and meteorological conditions. Gustin (*46*) assumed that 30% of deposited mercury was re-emitted in her analysis of natural mercury emissions in Nevada. Recent data from the Experimental Lakes Area in Canada suggest that 8% of applied mercury was re-emitted the first year and that 16% of "native" mercury was re-emitted (*47*). Landis and Keeler (*48*) estimated mercury deposition to and evasion from Lake Michigan using data from the Lake Michigan Mass Balance Study. They estimated that, on an annual basis, evasion of Hg(0) from the lake amounted to 38% of wet and dry deposition of mercury to the lake. A lower percentage of re-emitted mercury leads to a larger fraction of direct natural mercury emissions if the direct anthropogenic and total global emissions are fixed (see Figure 1).

For this study, we selected three scenarios. In our base scenario, we assumed that 50% of deposited mercury is re-emitted to the atmosphere; this corresponds to a ratio of current/pre-industrial emissions, R, of 3, that is, similar to that of Mason and Sheu (*37*). In one alternative scenario (hereafter referred to as the lower bound scenario), we assumed that 33% of deposited mercury is re-emitted; this corresponds to $R = 2$. This ratio of current/pre-industrial emissions is toward the low part of the range reported in the literature. On the other hand, the re-emitted fraction may be more consistent with the preliminary estimates discussed above. In the other alternative scenario (hereafter referred to as the upper bound scenario), we assumed that 56% of deposited mercury is re-emitted; this corresponds to $R = 4$, that is, a ratio of current/pre-industrial emissions identical to that of Lamborg et al. (*42*).

The emissions from land and oceans vary little among those scenarios because the mercury background emissions are redistributed among their direct natural emissions, re-emissions of natural mercury, and re-emissions of anthropogenic mercury. Emissions from land range from 2266 Mg/year (upper bound scenario) to 2360 Mg/year (lower bound scenario), whereas emissions from oceans range from 1908 Mg/year (lower bound scenario) to 2002 Mg/year (upper bound scenario).

Figure 2 presents a summary of the global mercury budget for our base emission scenario. Because it is not possible to differentiate between natural and anthropogenic mercury after it has been emitted, re-emissions must necessarily include both natural and anthropogenic mercury. These re-emissions are allocated to both natural and anthropogenic emissions, proportionately to the direct emissions.

TABLE 2. Comparison of Recent Global Budgets for Atmospheric Mercury

emissions	Bergan et al. (*49*)	Mason and Sheu (*37*)	Lamborg et al. (*42*)	this work, base	this work, lower bound	this work, upper bound
direct anthropogenic (Mg/year)	2160	2400		2143	2143	2143
re-emitted anthropogenic (Mg/year)	2000	2090	4800	2134	1067	2670
natural from land[a] (Mg/year)	500	810	1000	1180	1805	878
natural from oceans[a] (Mg/year)	1400	1300	600	954	1396	720
total (Mg/year)	6060	6600	6400	6411	6411	6411
re-emissions/deposition (%)	50	47	NA[b]	50	33	56
current/pre-industrial emissions	3	3.1	4	3	2	4

[a] Including re-emission of natural mercury. [b] Not available.

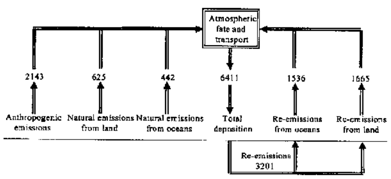

FIGURE 2. Schematic summary of the global atmospheric mercury cycle for the base emission scenario (annual emission and deposition rates are in Mg/year).

Table 2 compares some recent global mercury budgets. Direct anthropogenic emissions range from 2143 to 2400 Mg/year. Natural land emissions (including re-emissions of natural mercury) range from 500 Mg/year (*49*) to 1805 Mg/year (lower bound scenario). Natural emissions from oceans (including re-emissions of natural mercury) range from 600 Mg/year (*42*) to 1396 Mg/year (lower bound scenario). Re-emissions of anthropogenic mercury range from 1067 Mg/year (lower bound scenario) to 2670 Mg/year (upper bound scenario). The ratio of current emissions to pre-industrial emissions of our base scenario is consistent with those used by Bergan et al. (*49*) and Mason and Sheu (*37*). The percentage of deposited mercury that is re-emitted in our base scenario is also consistent with those used by Bergan et al. (*49*) and by Mason and Sheu (*37*).

Performance Evaluation of the Global and Continental Models

Prior to the conducting of a source attribution analysis with this global/continental modeling system, it is essential to evaluate the performance of the two CTMs to ensure that they can reproduce the major characteristics observed in measurements of mercury concentrations and deposition fluxes as well as to assess their current limitations. To that end, we present below the evaluation of the global and continental model simulation results against available data.

Global Mercury Chemical Transport Model. Figure 3 presents the global ground-level annual-average concentrations of Hg(0), Hg(II), and Hg(p). The surface Hg(0) concentrations display a strong latitudinal gradient with background concentrations mostly in the range of 1.2−1.6 ng/m^3 in the southern hemisphere and mostly in the range of 1.6−1.9 ng/m^3 in the northern hemisphere. Concentrations >1.7 ng/m^3 are simulated over the large source areas of eastern Europe and eastern Asia. In the southern hemisphere, South Africa shows up as a large source area with Hg(0) concentrations up to 1.6 ng/m^3.

The Hg(II) concentrations show stronger spatial variations than the Hg(0) concentrations due to their stronger correlations with source areas, such as South Africa, North America, Europe, and Asia. The highest Hg(II) concentrations (>100 pg/m^3) are simulated over eastern China, due to the fact that Asia accounts for half of the global anthropogenic emissions.

The Hg(p) concentrations are solely of anthropogenic origin and, therefore, they provide footprints of the major source areas. Concentrations of Hg(p) in eastern Asia are in the range of 100−200 pg/m^3.

The average atmospheric lifetime of mercury was calculated to be 1.2 years. Table 3 presents a comparison of simulated mercury concentrations with mercury concentrations measured at a variety of locations. Those concentrations measured in North America are compared below with the results of the continental simulation. In Europe, the simulated concentrations of total gaseous mercury (TGM) [represented by the sum of Hg(0) and Hg(II) in the model] are within 6% (0.12 ng/m^3) of the measurements at the Mace Head site on the west coast of Ireland and at various sites in Germany, but are underpredicted by about 30% (0.8 ng/m^3) in Slovakia and by 12% (0.25 ng/m^3) in Tuscany, Italy, and overpredicted by about 9−17% (0.14−0.25 ng/m^3) in Sweden. The underpredictions are likely due to the coarse spatial resolution of the global model, which tends to dilute primary emissions of mercury. The overprediction in Scandinavia may be due to an underestimation of dry deposition over forested areas in the global model. In Asia, the model underpredicts TGM concentrations by 40−50% (1−2 ng/m^3) in Korea and underpredicts by several nanograms per cubic meter in southern Kyushu, Japan, and in Beijing, China. These large underpredictions result from the fact that those latter measurements do not reflect background concentrations but rather correspond to the local impacts of nearby sources. For example, in Beijing, most homes burn coal for heating and cooking, thereby causing large emissions of mercury within a small area. Measurements in such an area will then reflect primarily local emissions. In southern Kyushu, Japan, the measurements were taken near an active volcano. This volcano is an important local source of mercury that is diluted within the global model coarse resolution. The simulated TGM concentration of 1.48 ng/m^3 in the Amazon is consistent with the range reported here for clean conditions. The model underpredicts the TGM concentration in South Africa by 0.25 ng/m^3. The TGM concentrations measured in the southern Atlantic Ocean are correctly predicted. However, the TGM concentrations measured in the northern Atlantic Ocean tend to be underpredicted by 20%. Thus, the model correctly predicts the direction of the north/south gradient in TGM concentrations but tends to underestimate the slope of that gradient. The Hg(0) concentrations measured in marine air at Cheeka Peak Observatory, WA, are representative of concentrations over the Pacific Ocean. The model correctly predicts the range of observed Hg(0) concentrations and reproduces the summer/winter seasonality. However, both RGM and TPM in the marine boundary layer are overpredicted by the model.

The simulated TPM concentration in Changchun, China, is at the lower range of the measurements because the coarse

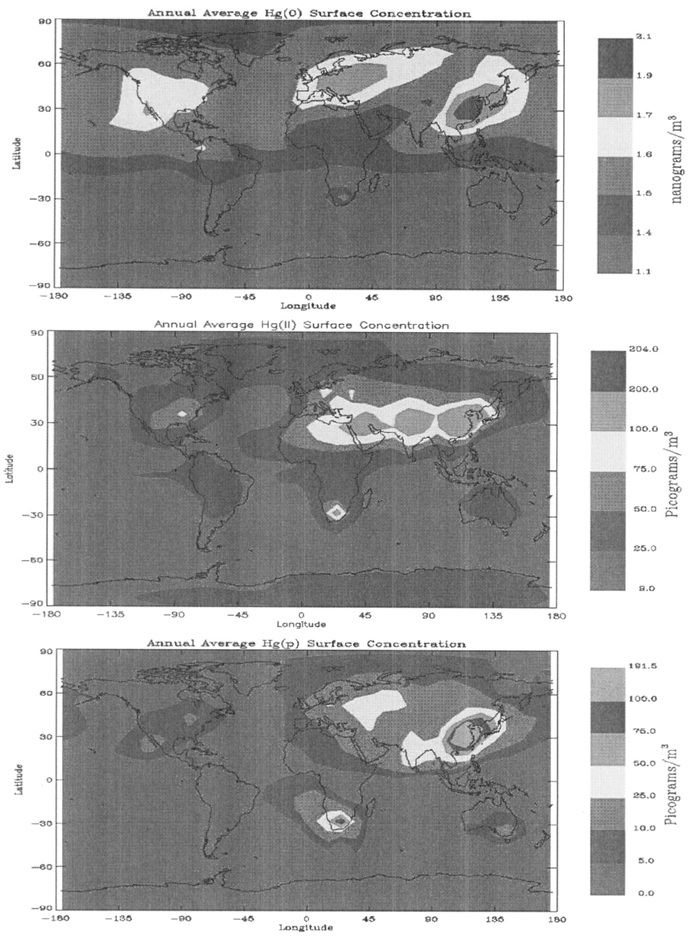

FIGURE 3. Global annual-average surface concentrations of Hg(0) (ng/m^3, top), Hg(II) (pg/m^3, middle), and Hg(p) (pg/m^3, bottom).

grid size dilutes the impact of local sources. The measurements conducted in Tuscany included speciated mercury concentrations. The model appears to overpredict the reactive gaseous mercury (RGM) concentration [represented by Hg(II) in the model] and to underpredict the total particulate mercury (TPM) concentration [represented by Hg(p) in the model]. This suggests that some RGM may adsorb to atmospheric particulate matter (PM), a process that is simulated in the cloud droplets but is assumed to be reversible (i.e., in the model, RGM returns to the gas phase after evaporation of the cloud droplets).

Continental Mercury Chemical Transport Model. Figure 4 depicts the annual-average concentrations of Hg(0), Hg(II), and Hg(p) over the contiguous United States. Maximum Hg(0) concentrations reach 4.4 ng/m^3. Overall, Hg(0) concentrations are high (>2 ng/m^3) in the western United States because of natural emissions and re-emissions of mercury deposited mainly via precipitation, low in the central United States (<1.7 ng/m^3), and moderately high (>1.7 ng/m^3) in the eastern United States because of anthropogenic emissions. For the most part, Hg(II) concentrations are higher in the eastern United States than in the western United States,

TABLE 3. Comparison of Observed and Simulated Mercury Concentrations (ng/m³)

location	period	species	observation[a]	simulation	refs
			United States		
Cheeka Peak Observatory, WA; marine air	May 2001–May 2002; spring; summer; fall; winter	Hg(0)	1.54; 1.61; 1.54; 1.51	1.60; 1.60; 1.55; 1.55	*50*
		RGM	0.0016; NA; <0.0016; <0.0016	0.013; 0.012; 0.0096; 0.032	
		TPM	0.0005; <0.0004; NA; NA	0.004; 0.002; 0.003; 0.0055	
Cheeka Peak Observatory, WA; continental air	May 2001–May 2002; spring; summer; fall; winter	Hg(0)	1.46; 1.50; 1.49; 1.47	2.15; 2.17; 2.02; 2.00	*50*
		RGM	0.0027; NA; 0.002; <0.0016	0.011; 0.017; 0.007; 0.007	
		TPM	0.0015; 0.0029; NA; NA	0.002; 0.0034; 0.0019; 0.0022	
Steamboat Springs, NV	Sept 1997	TGM	2–200	2.27	*32*
Cheasapeake Bay, MD	1997–1999	Hg(0)	1.89	1.85	*51*
		RGM	0.04	0.06	
		TPM	0.02	0.01	
Eagle Harbor, MI	Aug 1997	TGM	1.2	1.6	*52*
		TPM	0.008	0.003	
Dexter, MI	Oct 1997; Sept 1998	TGM	1.5; 1.5	2.3; 2.3	*52*
		TPM	0.014; 0.013	0.003; 0.003	
Everglades, FL	March 1999	TGM	1.9	1.7	*52*
		TPM	0.025	0.005	
Caryville, FL	1995–1996	TPM	0.006	0.003	*53*
Lake Barco, FL	1994–1996	TPM	0.006	0.003	*53*
southern Florida	1994–1996	TPM	0.002–0.009	0.006	*53*
Barrow, AK	Feb 1999–April 2001	RGM	0.024	0.021	*54*
Baltimore, MD	Feb 1999–April 2001	RGM	0.023	0.183	*54*
Durham, NC	Feb 1999–April 2001	RGM	0.016	0.034	*54*
Everglades, FL	Feb 1999–April 2001	RGM	0.015	0.060	*54*
Pompano Beach, FL	June 2000	TGM	2.0	2.1	*55*
		RGM	0.005	0.020	
		TPM ($PM_{2.5}$)	0.002	0.005	
		TPM (PM_{10})	0.015		
			Canada		
Alert, NT	1997–1999	TGM	1.55	1.52	*56*
Esther, AB	1997–1999	TGM	1.69	1.39	*56*
Mingan, PQ	1997–1999	TGM	1.62	1.57	*56, 57*
Reifel Island, BC	1997–1999	TGM	1.69	2.60	*56*
Burnt Island, ON	1997–1999	TGM	1.58	1.66	*56*
St. Anicet, PQ	1997–1999	TGM	1.72	1.91	*56, 57*
St. Andrews, NB	1997–1999	TGM	1.43	1.45	*56*
Kejimkujik, NS	1997–1999	TGM	1.33	1.6	*56*
Egbert, ON	1997–1999	TGM	1.65	2.15	*56*
Point Petre, ON	1997–1999	TGM	1.9	1.74	*56*
L'Assomption, PQ	1998	TGM	1.79	2.48	*57*
Villeroy, PQ	1998	TGM	1.62	1.65	*57*
			Europe		
Mace Head, Ireland	1995–2001	TGM	1.75	1.64	*58*
Wank Mountain, Germany	1996	TGM	1.82	1.81	*59*
Slovak Republic	1996–1997	TGM	2.63	1.86	*60*
Tuscany, Italy	June 1998	TGM	2.0	1.75	*61*
		RGM	0.022	0.087	
		TPM	0.056	0.021	
Neuglobsow, Germany	1998–1999	TGM	1.98	1.86	*62*
Zingst, Germany	1998–1999	TGM	1.82	1.86	*62*
Roervik, Sweden	1998–1999	TGM	1.54	1.68	*62*
Aspvreten, Sweden	1998–1999	TGM	1.43	1.68	*62*
northwestern Europe and Mediterranean	1998–1999	RGM	0.010–0.065	0.017–0.083	*62*
		TPM	0.012–0.040	0.004–0.027	
			Asia		
western Korea	March 2001	TGM	3.72	2.13	*63*
Seoul, Korea	Sept 1997; May–June 1998	TGM	3.43–3.94	2.03; 2.12	*64*
Kyushu, Japan	1996	TGM	10.8	1.70	*65*
Beijing, China	Jan, Feb, Sept 1998	TGM	6.2–24.7	2.26; 2.38	*66*
Changchun, China	July 1999–Jan 2000	TPM	0.02–2	0.062	*67*
			South America		
Amazon	Aug–Sept 1995	TGM	0.5–2	1.48	*68*
			Africa		
Cape Point, South Africa	Dec 1999–Jan 2000	TGM	1.29	1.04	*69*
			Atlantic Ocean		
Northern Hemisphere	Dec 1999–Jan 2000	TGM	2.0	1.6	*70*
Southern Hemisphere	Dec 1999–Jan 2000	TGM	1.3	1.3	*70*

[a] Mean value of measurements.

although a few isolated grid cells in the west show concentrations >50 pg/m³. Hg(II) concentrations are mostly <100 pg/m³, except for a few grid cells that show concentrations in the range of 100–183 pg/m³. In northern California, the high Hg(II) concentration corresponds to the Geysers area, where we assumed 30% Hg(II) for the emissions; high Hg(II)

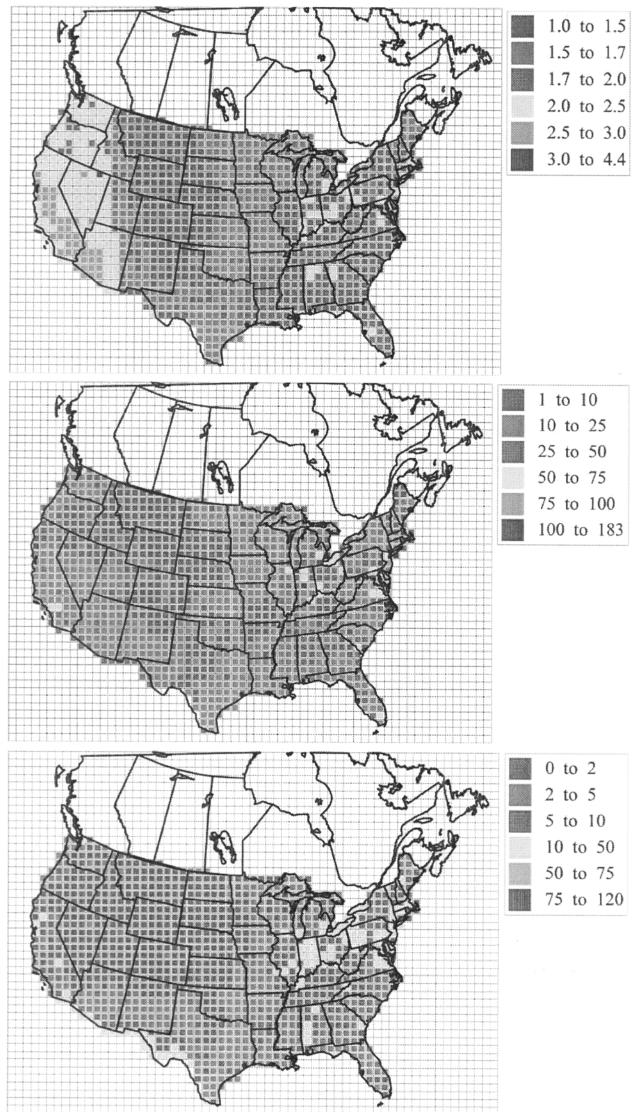

FIGURE 4. U.S. annual-average surface concentrations of Hg(0) (ng/m^3, top), Hg(II) (pg/m^3, middle), and Hg(p) (pg/m^3, bottom).

concentrations have been measured in an area with some geothermal activity, Sulfur Banks, CA (*46*). Hg(p) concentrations reach 120 pg/m^3 in some grid cells but are primarily <50 pg/m^3.

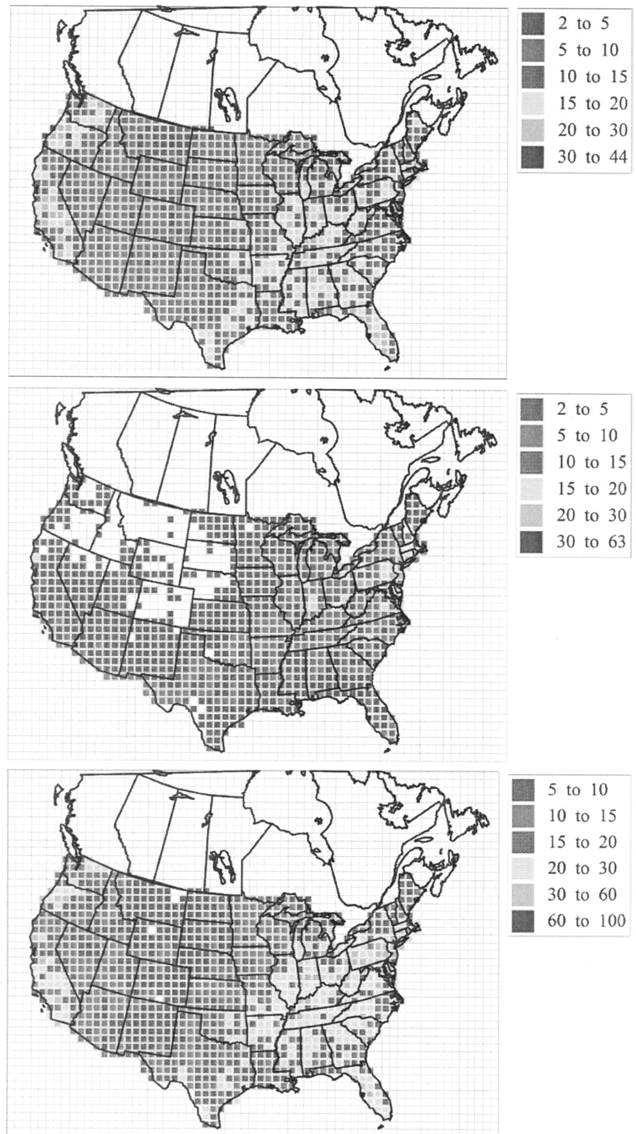

FIGURE 5. U.S. annual wet deposition flux ($\mu g/m^2$-year, top), dry deposition flux ($\mu g/m^2$-year, middle), and total deposition flux of total Hg ($\mu g/m^2$-year, bottom).

Figure 5 depicts the wet, dry, and total (i.e., wet plus dry) mercury deposition fluxes over the contiguous United States. Wet deposition fluxes are highest in the western and eastern United States. The high wet deposition fluxes on the west coast are due to the global Hg(II) concentrations at the upwind boundary (25 pg/m^3 on average) as well as high precipitation along the mountain ranges of the Cascades and Sierra Nevada. The high wet deposition fluxes in the eastern United States result from the influence of local/regional sources (e.g., in the northeast) or high precipitation (e.g., Florida). Dry deposition fluxes are highest in the northeastern United States. The high (15–20 μg/m^2-year) dry deposition flux in northern California corresponds to the Geysers area. The high dry deposition fluxes in the northeast result from the impacts of local/regional emission sources. The total deposition fluxes reflect the characteristics mentioned above for the wet and dry deposition fluxes.

A comparison of observed and simulated concentrations of mercury is presented in Table 3 for several locations in the United States and Canada. In the United States, TGM concentrations are correctly predicted in the east (in Florida and Maryland) but are overpredicted in the midwest and northwest. In Nevada, the model prediction is consistent with the lower range of the measured concentrations; the high measured concentrations reflect the fact that the data were collected over mercury-enriched areas that are not resolved spatially by the model. In Canada, the model shows good agreement (i.e., within 0.1 ng/m^3) for TGM at five sites (Alert, Mingan, Burnt Island, St. Andrews, and Villeroy), underpredicts at two sites by up to 0.3 ng/m^3 (Esther and Point Petre), and overpredicts at the other five sites by 0.2–0.9 ng/m^3. The large simulated concentration of 2.6 ng/m^3 at Reifel Island is due to the presence of several large sources (a chlor-alkali plant and incinerators) in the Seattle area. The large simulated concentration of 2.48 ng/m^3 at L'Assomption is due to the fact that Montreal is located in the same grid cell.

The model correctly predicts the RGM concentration at Barrow, AK, but overpredicts RGM concentrations within the contiguous United States. The significant overprediction in Baltimore is in part due to the local impact of a municipal waste incinerator in the 1998 model simulation; the implementation of emission controls in the 1999–2000 period is likely reflected in the measurements. The overall overprediction of RGM may be due to the fact that some Hg(II) is actually adsorbed to atmospheric PM [see discussion of Tuscany measurements above and discussion of Mace Head measurements by Seigneur et al. (*1*)] and is not measured as RGM but may be present as TPM. This is consistent with the fact that the model tends to underpredict TPM at most sites. In Maryland, where both RGM and TPM were measured concurrently, the model agrees well with the measurements of the sum of RGM and TPM. However, in Washington state, the model overestimates both RGM and TPM, although it correctly predicts greater RGM than TPM concentrations in continental air and in marine air.

Mason et al. (*71*) reported fluxes of mercury wet deposition at four sites (one urban and three rural) in Maryland. A direct comparison with the simulated values is not feasible because the observed annual deposition fluxes are reported for May 1997–May 1998, whereas the model simulation is for the year 1998, and there is considerable year-to-year variability. It is, nevertheless, interesting to compare differences between the urban site and the rural sites. Mason et al. report that wet deposition at the urban site is 2–3 times greater than at the rural sites. The model simulation shows a similar trend with wet deposition at the urban site being 1.7–4.4 times greater than at the rural sites.

For North America, we also compared modeled wet deposition fluxes of mercury to observations available for 1998 from the Mercury Deposition Network (MDN). Figure 6 presents the comparison for all 30 individual MDN sites. Some aspects of model performance improved from the previous version of the model (*72*). The coefficient of determination (r^2) increased from 0.45 to 0.50, the normalized error decreased from 28 to 25%, but the magnitude of the normalized bias increased slightly from −9 to +11%.

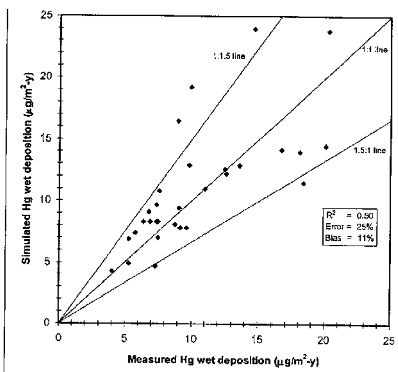

FIGURE 6. Comparison of simulated and observed mercury wet deposition fluxes for 1998 at individual MDN sites.

Global Source Attribution

Emission Sensitivity Simulations. Mercury is a global pollutant, and a significant fraction of the mercury deposition occurring within the United States is due to anthropogenic emissions from other continents, natural emissions, and re-emissions of mercury. It is, therefore, of interest to simulate the relative contributions of these global sources to mercury deposition in the United States. To that end, we conducted several simulations to estimate the following: (1) the effect of direct anthropogenic emissions (i.e., without their re-emissions) from individual continents; (2) the effect of direct natural emissions (i.e., without their re-emissions) from land and the oceans; (3) the effect of both direct and indirect (i.e., including re-emissions) anthropogenic emissions from individual continents, and (4) the effect of both direct and indirect (i.e., including re-emissions) natural emissions from land and the oceans.

To simulate the effect of direct anthropogenic or natural emissions, a global model simulation was conducted with only the source category of interest (i.e., anthropogenic emissions from a continent or natural emissions). The results of that simulation were then used to provide the boundary concentrations of the North American TEAM simulation reflecting the contribution of that source, and a TEAM simulation was then conducted to simulate the effect of that source. This approach is appropriate because the atmospheric transport and transformation processes of mercury are linear with respect to mercury species, and the results of simulations for individual sources are consequently additive.

The effect of the indirect component (i.e., re-emissions) of anthropogenic and natural sources was simulated as follows. A global simulation was conducted to obtain the contribution of re-emissions to the TEAM boundary conditions, and a TEAM simulation was conducted to calculate the corresponding contribution to mercury deposition in the United States. These re-emissions were then allocated

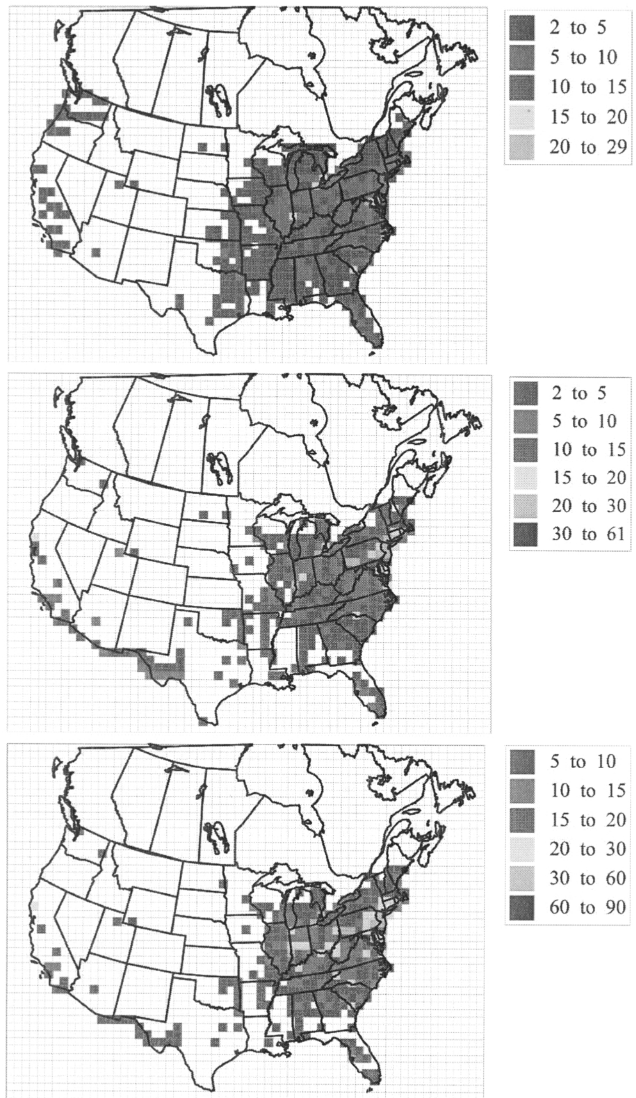

FIGURE 7. Annual wet (top), dry (middle), and total (bottom) deposition fluxes of total Hg ($\mu g/m^2$-year): contribution of North American anthropogenic emissions.

proportionately to the anthropogenic and natural sources according to their respective emission levels (e.g., in the base case, two-thirds of re-emissions were allocated to anthropogenic emissions and one-third to natural emissions; Asia

was allocated 53% of the anthropogenic fraction, North America, 10%, and so on).

In the results presented below, we consider deposition of only Hg(II) and Hg(p) following the methodology of Seigneur et al. (*3*).

Simulation Results. The contribution of North American direct anthropogenic emissions only (i.e., without the corresponding re-emissions) to mercury deposition occurring in the United States is presented in Figure 7 for wet, dry, and total deposition, respectively. It corresponds to a TEAM simulation conducted with North American emissions and boundary conditions corresponding to these emissions. The contribution to wet deposition west of the Mississippi river is <5 $\mu g/m^2$-year except for two grid cells that have wet deposition fluxes between 5 and 10 $\mu g/m^2$-year. In the eastern United States, the contribution is mostly in the range of 2−10 $\mu g/m^2$-year but reaches 29 $\mu g/m^2$-year in the mid-Atlantic region. The same patterns appear for dry deposition, but the contribution is greater in the eastern United States (up to 61 $\mu g/m^2$-year) because Hg(II) emissions can deposit locally and regionally via dry processes, whereas some fraction gets reduced to Hg(0) in the presence of clouds, which is not removed via wet deposition. Contributions of anthropogenic North American sources to total deposition of mercury are primarily limited to the eastern United States, with the largest contributions in the northeastern United States.

The contributions of direct anthropogenic emissions from other continents, direct natural emissions, and re-emissions to mercury deposition in the United States were simulated similarly, that is, by conducting a TEAM simulation with boundary conditions corresponding to the source of interest and with no North American emissions. Re-emissions were attributed to anthropogenic and natural emissions as described above. The contributions of anthropogenic and natural emissions, including their corresponding re-emissions, to wet, dry, and total mercury deposition in the contiguous United States are presented for the base emission scenario in Figure 8.

On average, North American anthropogenic emissions are calculated to contribute 30% to mercury total deposition in the contiguous United States; other anthropogenic emissions contribute 37%, with Asia contributing the most (21%), whereas natural emissions account for 33%. The results differ for the other two emission scenarios. For the lower bound scenario, which includes equivalent amounts of global natural and anthropogenic emissions, natural emissions dominate with 51% of mercury total deposition in the contiguous United States. North American anthropogenic emissions are calculated to contribute only 25%; other anthropogenic emissions contribute 24%, with Asia contributing the most (14%). For the upper bound scenario, which includes 3 times more anthropogenic emissions than natural emissions, North American anthropogenic emissions are calculated to contribute 32% of mercury total deposition in the contiguous United States. Other anthropogenic emissions contribute 42%, with Asia contributing 25%. Natural emissions account for only 26%. These results provide some estimate of the uncertainties associated with the relative distribution of background emissions between direct natural emissions and re-emissions of deposited mercury.

The contributions of anthropogenic and natural emissions to mercury deposition at specific receptors distributed across the continental United States were also analyzed. Nineteen receptors that represent a selection of areas that are potentially sensitive to mercury deposition were chosen for this analysis. Their locations are depicted in Figure 9. Those receptors are (in the order of their identification number in Figure 9): Brule River, WI (MDN site WI08); Devil's Lake, WI (MDN site WI31); Sleeping Bear Dunes National Lakeshore, MI; Lake Erie, PA (MDN site PA30); Huntington Wildlife

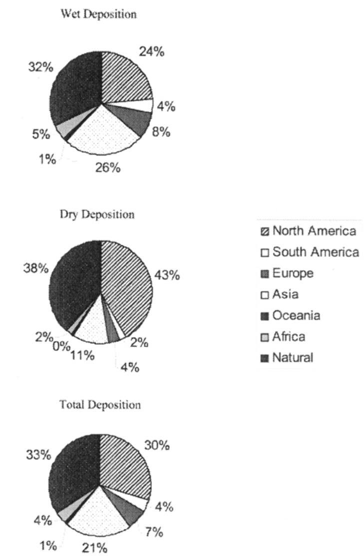

FIGURE 8. Relative contributions (%) of anthropogenic continental emissions and natural emissions from land and oceans to total mercury deposition over the contiguous United States for the base emission scenario.

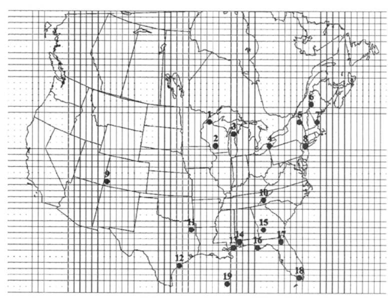

FIGURE 9. Locations of the receptor grid cells.

Refuge, NY (MDN site NY 20); Greenville Station, ME (MDN site ME09); New Castle, NH (MDN site NH05); Pines Lake, NJ; McPhee/Narraguinnep Reservoirs, CO [a total maximum daily load (TMDL) study site]; Great Smoky Mountains National Park; Longview, TX (MDN site TX21); upper Lavaca Bay, TX; Louisiana/Mississippi southern border; Mobile Bay, AL; Ichawahoa-chaway Lake, GA; Apalachicola Bay, FL; Lake Barco, FL; Everglades National Park, FL (MDN site FL11); and the Gulf of Mexico. Results for mercury deposition are presented in Figure 10.

At the reservoirs in southwestern Colorado, North American anthropogenic emissions contribute only 14%. The largest anthropogenic contribution comes from Asia with 27%.

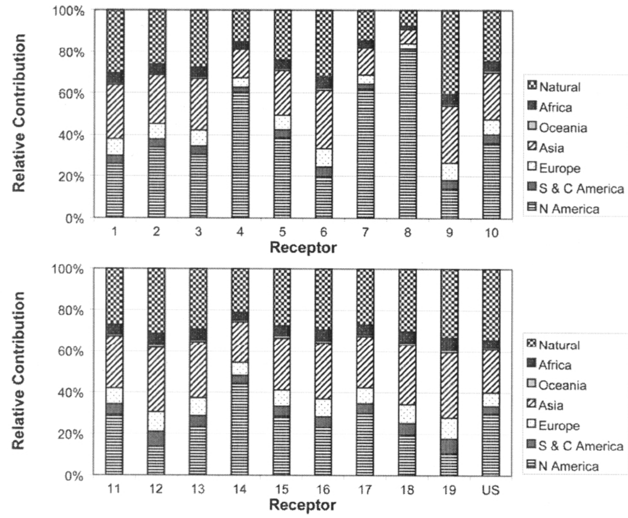

FIGURE 10. Relative contributions (%) of anthropogenic continental emissions and natural emissions to total mercury deposition at selected receptors for the base emission scenario.

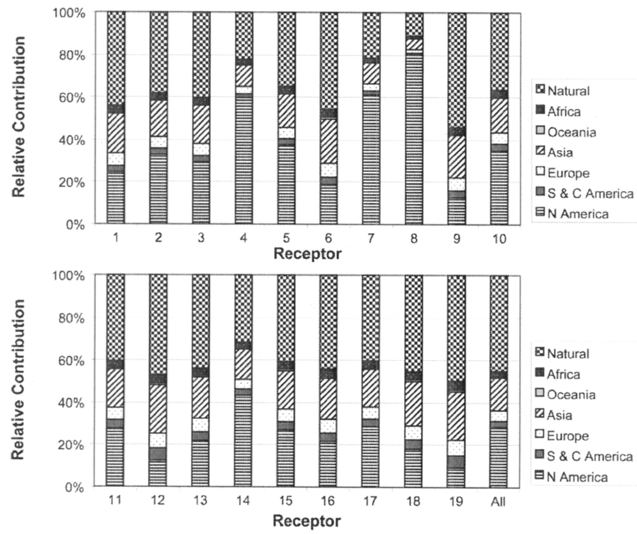

FIGURE 11. Relative contributions (%) of anthropogenic continental emissions and natural emissions to total mercury deposition at selected receptors for the lower bound emission scenario.

Natural emissions from land and the oceans account for 40%. In the Adirondacks, North American emissions account for the dominant fraction with 39% of total mercury deposition. Asian anthropogenic emissions still contribute signifi-

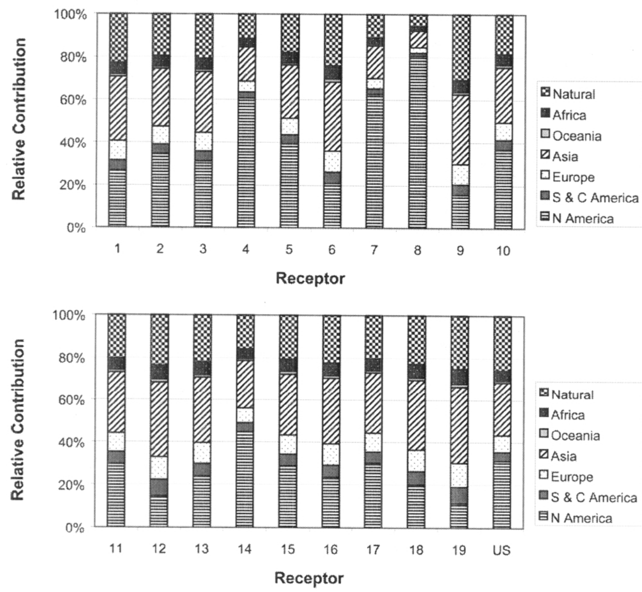

FIGURE 12. Relative contributions (%) of anthropogenic continental emissions and natural emissions to total mercury deposition at selected receptors for the upper bound emission scenario.

cantly with 22%; natural emissions account for 24%. At Devil's Lake, WI, North American anthropogenic emissions contribute 34% of mercury deposition with other global anthropogenic emissions contributing 40%; natural emissions contribute 26%. In the Everglades National Park, FL, North American emissions contribute only 20%. These results show a contribution from local and regional sources that is significantly less than previously estimated. For example, Dvonch et al. (*73*) used a receptor modeling approach with 1995 data from the Southern Florida Atmospheric Mercury Monitoring Study (SoFAMMS) to estimate that ~70% of mercury deposition in Florida originated from local sources in 1995. Guentzel et al. (*53*) used box model calculations based on 1992–1996 data from the Florida Atmospheric Mercury Study (FAMS) to estimate that 30–46% of mercury deposition may originate from local anthropogenic sources and the remainder from the global background. Our results show a much greater contribution from the global background and suggest that Asia (29% contribution) rather than Europe (9% contribution) provides the dominant contribution. This can be explained by the fact that Asian emissions are greater than European emissions by about a factor of 3.5.

At the other 15 receptors, the contribution of anthropogenic emissions from North America to total mercury deposition ranges from 11% (Gulf of Mexico) to 80% (Pines Lake, NJ). Contributions from Asian anthropogenic emissions range from 7% (Pines Lake, NJ) to 32% (Gulf of Mexico). Natural emissions contribute between 8% (Pines Lake, NJ) and 40% (McPhee/Narraguinnep Reservoirs, CO).

Results from the lower bound and upper bound emission scenarios are presented in Figures 11 and 12, respectively. For the lower bound scenario, the contribution of anthropogenic emissions from North America to total mercury deposition ranges from 9% (Gulf of Mexico) to 80% (Pines Lake, NJ). Contributions from Asian anthropogenic emissions range from 5% (Pines Lake, NJ) to 23% (Gulf of Mexico and upper Lavaca Bay, TX). Natural emissions contribute between 11% (Pines Lake, NJ) and 59% (McPhee/Narraguinnep Reservoirs, CO). For the upper bound scenario, the contribution of anthropogenic emissions from North America to total mercury deposition ranges from 12% (Gulf of Mexico) to 81% (Pines Lake, NJ). Contributions from Asian anthropogenic emissions range from 8% (Pines Lake, NJ) to 36% (Gulf of Mexico). Natural emissions contribute between 6% (Pines Lake, NJ) and 31% (McPhee/Narraguinnep Reservoirs, CO).

Current models of the atmospheric fate and transport of mercury may overestimate the local and regional impacts of some anthropogenic emission sources (*72*). Therefore, the calculated contributions of anthropogenic North American emissions are likely to represent upper bounds of actual contributions.

Acknowledgments

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Supporting Information Available

Calculation of global Hg emissions budgets. This material is available free of charge via the Internet at http://pubs.acs.org.

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November 12, 2003

The Honorable Vernon Ehlers
Chairman
House Subcommittee on Environment, Technology, and Standards
2319 Rayburn House Office Building
Washington, DC 20515

Dear Mr. Chairman:

The Annapolis Center for Science-Based Public Policy is pleased to submit the following comments to the House Science Subcommittee on Environment, Technology, and Standards for inclusion in the hearing record for the hearing on Mercury that was held on Wednesday, November 5, 2003.

Please feel free to contact me if you have any questions about this issue or others.

Sincerely,

Harold M Koenig

Harold M. Koenig, M.D.
Chair and President, The Annapolis Center
Vice Admiral and Former Surgeon General, U.S. Navy, Ret.

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Comments by

The Annapolis Center for Science-Based Public Policy

Before the House Science Subcommittee on
Environment, Technology, and Standards
Hearing of November 5, 2003

The major points that The Annapolis Center for Science-Based Public Policy makes on mercury are the following:

- Mercury in mining and production in the United States stopped in 1991. Since then, industrial consumption of mercury has dropped by more than 50 percent.

- Most of the mercury deposited in U.S. water bodies comes from natural or man-made emission sources outside of our nation's borders. Therefore, mercury is a global issue, and reducing U.S. anthropogenic emissions (particularly coal-fired generating plants) will not significantly decrease the amount of mercury in fish harvested from U.S. waters.

- Women of child-bearing age can eat a variety of fish species to help them maintain good nutrition. Women in this category can safely consume 12 ounces a week (2 meals per week) of most fish species.

The Annapolis Center for Science-Based Public Policy is an independent, national non-profit educational organization that seeks to promote the use of science in energy, environmental, health, and safety decision-making. Recently, The Annapolis Center published a report entitled, "*Mercury in the Environment: The Problems, the Risks, and the Consequence*."

Since the late 18th century, humans have found many uses for mercury, including light bulbs, pesticides, batteries, paint, and thermometers and barometers. The ubiquitous and persistent nature of mercury has made it an environmental and human health concern over the past few decades. Because of this realization, laws were passed in the United States to protect its citizens from this toxic pollutant.

As a result, the nation's demand for mercury has significantly declined, and the mine production of primary mercury in the United States ceased in 1991. The closure of these mines has resulted in a significant reduction of the mercury released into the environment from the milling and roasting of the ores. However, a considerable amount of mercury is produced, traded and used internationally.

Mercury occurs naturally, and is dispersed into the environment by both natural and anthropogenic processes. The natural bio-geochemical global cycling of mercury

involves degassing the element from surface waters and soils, transporting it through the atmosphere, depositing back into the land and water, absorbing into the soil and sediment, and then its revolatilization from the land and water.

Approximately 2,700 – 6,000 tons of mercury are released annually into the atmosphere from the naturally-occurring degassing of Earth's oceans and crust. Another 2,000 – 3,000 tons are emitted annually by human activities. An estimated total of 144 tons of mercury entered the United States' environment in 1996 as a result of our nation's anthropogenic emissions representing about 3 percent of the total mercury released globally from human activities. On the other hand, Asia accounts for nearly half of the anthropogenic mercury emitted globally, and China's coal-fired power plants alone represent approximately 22 percent of these emissions. U.S. coal-fired electric utilities, the largest source of human related mercury emissions in this country, release approximately 40 tons annually. Although this accounts for slightly more than 30 percent of the anthropogenic mercury produced by this nation's point source emissions, the U.S. utility industry contributes less than 1 percent to the existing global pool of mercury each year. Other major sources are municipal waste combustors, medical waste incinerators and hazardous waste combustors.

Once this pollutant is released into the air, mercury vapor travels long distances and impact distant locations. Approximately two-thirds (107 tons) of U.S. generated mercury emissions are transported outside of our nation's borders. Roughly 60 percent of the total mercury deposited on the nation's soils and water bodies comes from U.S. anthropogenic air emissions. The remaining 40 percent comes from international human-made mercury emissions, natural sources and reemitted mercury from historic U.S. sources. The amount of mercury deposited over the United States increased rapidly from 1900 to 1950, and then declined about 2-3 fold between 1950 and the 1990s. Since 1995, however, even though mercury emissions from incinerators and other sources had decreased over the past 10 years, mercury deposition in most areas of the country has remained fairly constant.

The Electric Power Research Institute (EPRI) conducted a source attribution study using a global model to assess which continents contribute to the mercury deposition at three locations in the United States (Wisconsin, Florida and New York State). Over 50 percent of the mercury deposition in all three locations was attributed to background/natural emissions. The model shows the next largest contributions being from North America (with 20 – 25 percent of the total mercury emissions) and Asia (with 12 – 15 percent).

Because of all the unknowns and uncertainties in the environmental fate of mercury, there is no quantification of how much of the methylmercury in fish is directly a result of the atmospheric emissions of mercury from electric utility plants or any of the other mercury source categories. In addition, there are a host of factors that reduce the certainty of the values produced by the environmental fate and transport of mercury analyses and models.

Although the total amount of mercury delivered to a water body is quite small, it is readily absorbed by the organic material, such as bacteria and plankton, floating in the water. Its methylated form, mercury is ingested by the small fish that consume the methanogenic microorganisms, and these fish (and the methylmercury) are then eaten by larger fish and so on up the food chain. The amount of methylmercury in the organism bioaccumulates at each level of this chain, and such bioaccumulation can result in high

levels of methylmercury in some fish. In general, however, methylmercury levels in fish range from less than 0.01 parts per million (ppm) to 0.5 ppm.

Food consumption surveys found that persons 14 years and older had a daily mean intake of fish and shellfish of 0.03 – 0.04 ug/kg/day. Women who are among the top 5 percent of fish/shellfish consumers in the childbearing age category eat just over 100 grams per day, and have methylmercury exposures of about 0.16 ug/kg/day.

States, territories and Native American tribes have the primary authority in protecting citizens from the health risks of eating contaminated fish and wildlife. These governing bodies place consumption advisories on water bodies that contain high levels of toxic chemicals, such as mercury. Forty-four states issued mercury related fish advisories in 2001.

A spectrum of adverse health effects have been observed in humans who were exposed to methylmercury. The severity of these effects is largely dependent on the magnitude of the dose. When methylmercury is ingested, through eating contaminated fish for example, the toxin is almost completely absorbed into the bloodstream, and then distributed to all the tissues, including the brain.

During the 1950s and 1960s, two major episodes of methylmercury poisoning resulted from the long-term consumption of high levels of methylmercury in fish. The first occurred in the early 1950s among people in Minamata City, Japan. As a result of this exposure, 111 Japanese died or suffered nervous system damage symptoms that were referred to as "Minamata Disease." These children displayed severe psychomotor retardation while their mothers' showed either minor manifestations of poisoning or none at all. The second incident occurred in Niigata, Japan in 1965 where 120 people were poisoned.

Methylmercury poisoning also occurred in two separate incidents in Iraq involving the consumption of seed grains. The symptoms resulting from these Iraqi poisonings primarily involved the nervous symptoms. More than 6,500 Iraqis were hospitalized and 459 died. Both adults and children were affected.

Despite an association between the neurological problems and mercury exposure in Japan and Iraq, these examples are of relatively little relevance to the consumption of fish in the United States.

However, extrapolating from data collected from the high-dose exposure incidents in Japan and Iraq, the U.S. EPA derived a reference dose (RfD) for the amount of methylmercury that is safe to consume based on the developmental neurological effects observed in the children born to mothers exposed to these high doses. The U.S. EPA's reference dose is an estimate (with uncertainty) of a daily exposure to the population (including sensitive subgroups) that is likely to not cause an appreciable risk of deleterious effects during a lifetime. The U.S. EPA's RfD is 0.1 microgram per kilogram body weight per day (0.1 ug/kg/day).

In an attempt to establish a dose-response relationship between the severity of symptoms of mercury poisoning to the amount of fish consumed, large prospective epidemiological studies were conducted in New Zealand, the Faroe Islands and the Republic of the Seychelles. These three studies examined prenatal methylmercury exposure levels that

are within the range of the general U.S. population exposures, and evaluated the "subtle end points of neurotoxicity." As a result, the body of knowledge on brain development following the long-term exposure of small amounts of methylmercury has substantially increased. Although the Seychelles Islands main study found no significant association, investigators in both the Faroe Islands and New Zealand studies found that increased prenatal methylmercury exposure was associated with lower performance on neuropsychological tests.

After reviewing these studies, the NAS *Toxicological Effects of Methylmercury* Study determined that this RfD of 0.1 ug/kg/day is a "scientifically justifiable level" for the protection of the public's health. Based on the new information, the U.S. EPA revised how it now bases its RfD value for methylmercury on data from Faroe Island study. This RfD value includes a composite uncertainty factor of 10 to account for the pharmacokinetic variability and uncertainty in estimating an ingested mercury dose from cord blood mercury concentrations (UF = 3), and pharmacodynamic variability and uncertainty (UF = 3). (Note that these two factors only account for 3 x 3 = 9 UF, although the composite UF = 10).

In 1979, the FDA established an action level of 1.0 ppm in fish (which is based in part on an acceptable or tolerable daily intake of about 0.4 ug/kg/day). This action level limits consumers' exposure to methylmercury levels that are 10 times lower than the lowest levels associated with adverse effects - a safety factor of 10. In January 2001, the FDA issued recommendations for pregnant women and women of childbearing age suggesting that they avoid fish species with the highest concentrations of methylmercury.

The Agency for Toxic Substances and Disease Registry (ATSDR) set a methylmercury exposure concentration of 0.3 ug/kg/day for its minimal risk level (MRL). (U.S. EPA's RfD is three times more stringent than ATSDR's MRL.) An uncertainty factor of 4.5 has been applied to account for the uncertainty for human pharmacokinetic variability (1.5 UF), domain specific findings of the Faroe Islands study (1.5 UF) and human pharmacodynamic variability (1.5 UF).

There is little doubt that prolonged and intense mercury exposure can cause toxic effects, but like any other substance, the dose makes the poison. Arguments calling for reduction in the amounts of methylmercury in fish through regulations on mercury emissions from electric utilities and other emission sources would need to be based upon conclusive evidence that current methylmercury concentrations in fish are harmful, and further, that these emission sources contribute significantly to these methylmercury levels in fish. However, U.S. emission sources (particularly utilities) probably do not appreciably affect methylmercury levels in fish.

Further complicating the relationship between reducing mercury air emissions and the lowering of methylmercury concentrations in fish is the global nature of mercury in that it can travel great distances before being deposited, and much of the mercury deposited within our nation's borders is from international sources. Therefore, attempts to reduce mercury loads in particular bodies of water, or methylmercury concentration in fish, would require actions to reduce mercury emissions on a global scale, rather than a local or regional scale. If we are concerned about reducing the amount of anthropogenically produced mercury in the environment, our efforts should be focused primarily on reducing the emissions of those countries that emit the most mercury, Russia and the region of Southeast Asia. Also worth noting, because such a significant amount of the

total mercury emitted globally is from naturally-occurring sources, even if anthropogenic mercury emissions were drastically reduced, this may not produce the declines in mercury deposition and methylmercury levels in fish that are desired.

These arguments all need to be considered when deciding at what level of methylmercury in fish is deemed to be a justifiable level for the public health's protection. In addition, because many fish species in our nation's waters already exceeding the U.S. EPA's RfD of 0.1 μg/kg/day, using this health action level as a guide for our nation's environmental laws related to methylmercury would most likely produce more stringent standards for anthropogenic emissions of mercury. These tougher standards would most likely produce high costs for little benefit because of the complex, non-straightforward cause-and-effect, nature of mercury air emissions and methylmercury concentrations in fish. On the other hand, while the FDA's Action Level of 1.0 ppm and Fish Advisory ensure the public's health, the resulting mercury emissions and other mercury related standards would not be costly as those resulting from using the U.S. EPA's RfD as regulatory guidance. In addition, with the uncertainties in our knowledge and the models of the environmental fate and atmospheric deposition of mercury, at this point in time, we should use the FDA Action Level for guidance in our nation's environmental regulations and standards for mercury. Then, as we fill in the gaps of our knowledge and improve the models, this issue can be revisited to determine if basing mercury regulation on the FDA Action Level is developing beneficial results, or if it is necessary switch to the U.S. EPA's more stringent RfD as a mercury lawmaking guideline.

An exhaustive study has been released of 643 children from before birth to 9 years of age showing no detectable risk from the low levels of mercury their mothers were exposed to from eating ocean seafood. This study by scientists at the University of Rochester Medical Center is the latest in a series of updates on children who have been studied since their birth in 1989 and 1990 in the Republic of the Seychelles, an island nation in the Indian Ocean. The children have been evaluated five times since their birth, and no harmful effects from the low levels of mercury obtained by eating seafood have been detected. (The study appeared in the May 17, 2003 issue of ***The Lancet***.)

In conclusion, attempts to reduce methylmercury in fish will require actions on a global scale, and would be seriously flawed if they only focused on emissions from utilities in the U.S. In the meantime, the need for burdensome and costly regulations to reduce a yet uncertain risk to public health is neither necessary nor prudent.